# King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay

## Appendix A: Problem Formulation, Analysis Plan, and Field Sampling Work Plan
## A1: Problem Formulation

**Prepared by the**

**Duwamish River and Elliott Bay**

**Water Quality Assessment Team**

**February 1999**

Parametrix, Inc.
5808 Lake Washington Boulevard, NE
Kirkland, Washington 98033-7350

King County Department of Natural Resources
Wastewater Treatment Division &
Water and Land Resources Division
821 Second Avenue
Seattle, Washington 98104-1598

# TABLE OF CONTENTS

**Page**

# TABLE OF CONTENTS (CONTINUED)

# LIST OF FIGURES



# LIST OF TABLES

# LIST OF ACRONYMS

| | |
|---|---|
| AIDS | Acquired Immune Deficiency Syndrome |
| CDC | Center for Disease Control |
| COPC | Constituents of potential concern |
| CSO | Combined sewer overflow |
| DO | Dissolved oxygen |
| FDA | Food and Drug Administration |
| IDD | Insulin-dependent diabetes |
| IgA | Immunoglobulin antibody |
| NRDC | National Resource Defense Council |
| PAHs | Polycyclic aromatic hydrocarbons |
| PCBs | Polychlorinated biphenyls |
| RNA | Ribo-nucleic acid |
| RWSP | Regional Wastewater Services Plan |
| SCUBA | Self-contained underwater breathing apparatus |
| U.S. EPA | United States Environmental Protection Agency |
| WERF | Water Environment Research Foundation |
| WSDOE | Washington State Department of Ecology |
| WSDOH | Washington State Department of Health |
| WSDOF | Washington State Department of Wildlife |
| WQA | Water Quality Assessment |

# 1. INTRODUCTION TO THE PROBLEM FORMULATION

The Duwamish River and Elliott Bay together make up a highly industrialized and urbanized estuary. The estuary is located on the eastern shore of Puget Sound and is surrounded by the City of Seattle. It is the location of heavy industry and a major shipping center as well as being home to a diverse array of fish, bird, mammal, and plant species. It is also used for tribal subsistence fishing and for recreation. Pollutants can enter the estuary from a variety of sources including industrial and commercial activities, storm drains, combined sewer overflows, treatment plants, illegal dumping, atmospheric deposition, and groundwater. The Water Quality Assessment is an assessment of the ecological and human health risks from exposure to pollutants in the estuary, and what part of these risks are from combined sewer overflows (CSOs). The need for this assessment emerged as part of the long range wastewater planning process known as the Regional Wastewater Services Plan for King County (RWSP).

The Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay (WQA) is sponsored by King County Department of Natural Resources with an integrated project team from the Wastewater Treatment Division, Water and Land Resources Division, the Department of Ecology Northwest Regional Office, and the City of Seattle.

Washington State Department of Ecology (WSDOE) regulations require King County to control CSO discharges to an average of one discharge event each year at each CSO location during a year of average rainfall. CSOs are discharges of sanitary sewage combined with stormwater released directly into water bodies during heavy or long duration storms. Combined sewers are limited to the County's service area within the City of Seattle. Currently, King County has 16 CSOs that discharge into the Duwamish River and Elliott Bay. Control of CSOs is one of the major programs of the RWSP.

Estimates show achievement of WSDOE's one CSO-event-per-year regulation will cost the County $600 million. The high cost of complying with this regulation has prompted the County to assess the significance of risks caused by CSOs and the long term benefit of controlling CSOs. While the cost of CSO control is high, information to predict the environmental and human health benefits of the regulation is incomplete. The WQA team has been asked to identify the benefits of controlling CSOs.

This appendix describes the work done by the WQA project team, with advice from a peer review panel and a stakeholder committee, to develop the Elliott Bay and Duwamish River Water Quality Assessment. It is organized into two sections. The first, on the management goal for the estuary, presents the goal and the process used to establish it. The second, is the problem formulation for the water quality assessment. The problem formulation is the first phase of risk assessment and establishes the goals, breadth, and focus of the assessment.

# 2. PLANNING THE WATER QUALITY ASSESSMENT

The planning process focused on establishing clear and acceptable goals, determining the purpose of the risk assessment, and agreeing on the scope and complexity of the risk assessment.

The challenge for King County was to first find an approach to quantify and describe the harm that may be occurring to aquatic life, wildlife and humans who use the Duwamish River and Elliott Bay, and second, how that harm would be changed with the control of CSOs. The process of ecological and human health risk assessment provides such an approach.

Dialogue with King County Management and WSDOE resulted in agreement that a risk assessment approach would provide a means of describing the benefits to be achieved by controlling CSOs. A committee of stakeholders was formed and will provide valuable input to both agencies in making appropriate decisions concerning CSO control. The outcome of this assessment will describe the reduction in risks expected with control of CSOs in the Duwamish estuary and will inform decisions regarding priorities for the CSO control program.

## 2.1 Establishing Management Goal

One of the principal challenges facing the WQA Project team was to develop a management goal that could be supported by diverse members of the community. To meet this challenge, the WQA project team worked with a stakeholder committee, whose members included community councils, businesses, government, industry, the Tribes, and environmental groups, to determine what was valued in terms of the Duwamish River and Elliott Bay.

The purpose of the risk assessment is to determine the benefit to the ecosystem and human health that can be achieved by control of CSOs in the Duwamish River and Elliott Bay. The proposed management goal for this project is as follows:

*Design a CSO control strategy whose goal is to continuously protect and improve water, sediment, and habitat quality. Indicators of achieving this goal are abundant, diverse, and healthy biological communities and enhanced recreational, commercial, and cultural use of the resources.*

## 2.2 Management Decisions

Decisions will be made by the King County Executive, King County Council, and WSDOE after considering the recommendations of the regional stakeholders. The stakeholder committee for this project will submit a written report containing recommendations on CSO control to the King County Executive. The ultimate decision maker will be WSDOE.

A series of questions will be addressed based on the outcome of this study. They include:

- What is the significance of baseline risks to aquatic life, wildlife, and people who use the resources of the estuary?
- What is the significance of risks from CSOs?
- What should be the next steps for King County's CSO control program?
- Are there areas that require further investigation and dialogue?

## 2.3 Scope and Complexity of the Risk Assessment

The scope of this risk assessment is complex and will follow both the guidelines of the U.S. Environmental Protection Agency (U.S. EPA 1989, 1992, 1994, 1996) and the Water Environment Research Foundation (WERF) (Parkhurst et al. 1996). The major tasks to be completed in this assessment are listed below:

- Develop a highly collaborative stakeholder and public involvement strategy.
- Develop a Problem Formulation in consultation with the stakeholders.
- Select an appropriate hydrodynamic model, and collect field data to calibrate the model.
- Design and carryout a sampling program that allows characterization of the chemical, physical and biological stressors of the Duwamish River and Elliott Bay.
- Design and carry out a sampling program that allows characterization of the CSOs discharging to the river and bay.
- Model the fate and transport of stressors in these water bodies.
- Model the fate and transport of stressors assuming that CSOs have been controlled in accordance with Washington State's goal of no more than one event per CSO per year.
- Perform an ecological and human health risk assessment for baseline conditions and for conditions as they would be with control of CSOs but with all other source of stressors remaining the same.

The uncertainty inherent in this project will be described in the risk assessment and areas of greatest uncertainty will be identified. This project is designed based on information from a previous screening level assessment performed in 1995. This allows us to focus on the areas where we need the most additional data. As in all studies, there is never enough money or enough time to eliminate all uncertainty in the estimates of risk.

# 3. DUWAMISH RIVER/ELLIOTT BAY PROBLEM FORMULATION

To develop the problem formulation, a formal process was used to generate preliminary hypotheses about how CSOs and other sources of pollutants, or stressors, may affect the health of aquatic life, wildlife, and humans. Additionally, the formal process was used to develop a strategy to predict the change in ecological and human health responses between current levels of stressors and a reduction in stressor sources because of proposed management actions. In the estuary, stressors associated with CSOs and other human activities were identified and characterized. It was also necessary to evaluate historical records on the ecological and human resource characteristics of the estuary as well as the current status of ecological impacts from human activities. This information provides the basis for predicting ecological and human health responses to proposed management actions aimed at controlling CSOs.

The Duwamish River/Elliott Bay problem formulation is based on an assessment of available information that provides the foundation for risk assessment. A summary of key information is provided below. Based on the management goal and available information, assessment endpoints were selected by the WQA Team and Technical Subgroup of the Stakeholder Committee. These assessment endpoints were used as the focus in the development of conceptual models and the analysis plan.

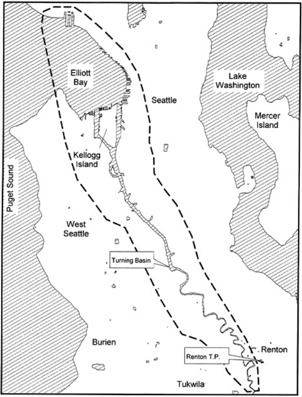
The initial step in problem formulation was to identify and assess available information on the characteristics of known and suspected stressors and observed ecological effects on the Duwamish River-Elliott Bay ecosystem. Relevant information on human health is included. This section provides a brief overview of information on the Duwamish River and Elliott Bay estuary. It highlights the information most relevant to understanding the risk assessment and is not intended to be comprehensive.

## 3.1 The Study Area

The study area includes the Green-Duwamish River from just upriver of the Renton Treatment Plant downstream to where it empties into Elliott Bay, a distance of about 24 km (Figure 3-1). It includes that portion of Elliott Bay east of a line drawn northward from Duwamish Head to Magnolia Bluff. The entire study area can be considered an estuarine system, that is, an aquatic system that exhibits both marine and freshwater characteristics. The upriver portion of the study area is primarily a freshwater river with tidal influence while the seaward boundary of the study area in Elliott Bay is primarily marine with a variable freshwater layer, especially in the winter months during periods of higher river flow.

### 3.1.1 The Duwamish River

The lower Duwamish River, from the river mouth to 13 km upstream from Harbor Island, is a highly industrialized salt wedge type estuary. This area is influenced by river flow and by tidal effects.




Water Quality Assessment Area - - - - -



**Figure 3-1.**
**Water Quality**
**Assessment Study Area**

As is typical of salt wedge estuaries, the Duwamish is characterized by a sharp interface between freshwater outflow at the surface and salt water inflow at depth. The layer of salt water is thicker near the river mouth, occupying most of the water depth, but tapers down toward the head (upriver portion) of the estuary. The location where salt water intrusion tapers off to zero is called the toe of the salt wedge. In the Duwamish River the toe of the salt wedge is located approximately 12 km upstream of the river mouth.

The lower portion of the river, below the turning basin (13 km from the mouth) has been straightened, dredged and armored with rocks in many areas to facilitate navigation and industrial development. The depth of the river portion varies from approximately 17 meters near the river mouth at Harbor Island to less than 1 meter in the upper river portion of the study area. Bottom sediments in the river range from sands to muds, depending on the sources of sediment and the current speeds. The flow of the river is largely controlled by releases from the Howard Hansen Dam, located in the upper portion of the Green River watershed. Summer flows in the river, gauged at Auburn, are in the range of 250 cubic feet per second (cfs). Winter flows average about 1,500 to 2,000 cfs, with peaks to more than 5,000 cfs during storm events.

### 3.1.2 Elliott Bay

Elliott Bay is approximately 21 $km^2$ and is located on the eastern shore of central Puget Sound. The bay opens to the main basin of Puget Sound to the west. Depths on the western Elliott Bay boundary are in the range of 150 to 180 meters while the depths close to the developed Seattle waterfront are 10 to 20 meters. A submarine valley enters the center portion of the bay from Puget Sound. A lobe of this valley runs southward along the eastern side of Duwamish Head and is about 80 meters deep. Natural shorelines with an intertidal zone are located along the western and northern shores of the bay. Sediments range from gravel and cobbles to fine muds, depending on the hydrodynamics and geographic area.

The open portion of Elliott Bay is dominated by Puget Sound marine water masses, with the freshwater layer from the Duwamish River limited to the upper five meters, or about five percent of the water column. In winter months this layer can be clearly seen in Elliott Bay from its brown sediment color. The river water is mixed with incoming Puget Sound water and enters the greater Puget Sound circulation. Sediment falls from the surface layer to the bottom in both Elliott Bay and in Puget Sound.

## 3.2 Historical Changes and Current State of Estuary

Over the last 125 years, the drainage area of the Duwamish River has been reduced by about 70 percent due to development and flow diversion. Most (98 percent) of approximately 1,270 acres of tidal marsh and 1,450 acres of flats and shallows, and all of about 1,250 acres of tidal wetland, have been eliminated (Blomberg et al. 1988). The intertidal habitat that remains in the Duwamish River is important for the survival of juvenile salmon, other predator fish, birds, and mammals that feed on invertebrates and small fish found in shallow areas of the study area. Kellogg Island is the largest remnant of intertidal habitat remaining in the Duwamish River Estuary (Tanner 1991). Habitat associated with the island includes high and low marsh, intertidal flats, and filled uplands (Canning et al. 1979). Kellogg Island provides important nesting and feeding habitat for waterfowl and other birds. Small patches of other intertidal areas occur in the estuary as marsh and unvegetated intertidal benches. Sections of natural shoreline only occur in the Duwamish River above the head of navigation, located at approximately River Mile 6 (Tanner 1991).

The nearshore environment of Elliott Bay once consisted of 2,100 acres of eelgrass and marsh habitats. Because of harbor development, eelgrass and marsh habitat have been reduced to about 54 acres (Stober and Pierson 1984). The marine waters of Elliott Bay provide habitat for demersal and pelagic marine fishes, invertebrates, marine mammals and birds, several commercially important anadromous fish (Chinook, Coho, and Chum salmon), and shellfish (geoduck, clam, crab, and shrimp). Nearshore habitats of Elliott Bay include the waterfront along downtown Seattle, with pilings and other human-made submerged structures, kelp beds off the northern shore of the bay; and eelgrass beds along the shoreline northeast of Alki Point. The majority of the nearshore benthic habitat is sand and sandy mud (Stober and Pierson 1984).

In addition to commerce, fishing (both recreational and commercial) and boating are pursued in both the Duwamish River and Elliott Bay, although swimming, wading, and beach activities also may occur on a very limited basis. Fishing activities in the Duwamish River include treaty gillnet fishing by the Muckleshoot Tribe and recreational angling from boats, fishing piers, and marinas. Public shoreline and water access occurs on the Duwamish River and also along the Seattle waterfront. The King County Health Department and the Washington Department of Health (WSDOH) recommend against collection of both fish and shellfish from urban shorelines (WSDOH 1993). Commercial harvesting of shellfish is not allowed in Elliott Bay because of high fecal coliform bacteria counts (Stober and Pierson 1984).

## 3.3 Sources of Stressors

Pollutants can enter the estuary from a variety of sources including industrial and commercial activities, storm drains, CSOs, treatment plants, illegal dumping, atmospheric deposition, and groundwater. This assessment will look closely at what part of the pollutants in the estuary are attributable to CSOs.

CSOs are discharges of untreated sewage and stormwater released directly into surface waters during periods of heavy rainfall (King County 1995b). Combined sewers, those which carry sanitary sewage and storm runoff in a single pipe, are found in much of metropolitan Seattle. Because combining systems was the standard engineering practice, all of Seattle’s sewers built from 1892 until the early 1940s were combined sewers. As newer sewers are installed in Seattle, storm water was separated from household, commercial, and industrial wastewaters.

CSOs serve as safety valves for the sewage treatment system. In combined systems, the trunk sewers and interceptors have fixed capacities. During periods of heavy rainfall, wastewater volumes may exceed the capacity of the sewer pipes to convey the wastewater to the treatment plant. To prevent damage to the system and to prevent sewers from backing up into homes, combined sewers are designed to overflow. Typically, overflows are designed to discharge to rivers and marine waters where the flushing action of tides and currents can disperse pollutants.

City of Seattle and King County CSOs occur within the study area in both the Duwamish River and Elliott Bay. Other CSOs occur in Lake Washington, Lake Union, and the Ship Canal. These locations are shown in Figure 3-2. From 1981 to 1983, nearly 2.4 billion gallons of untreated sewage were discharged from this system each year. As a result of control efforts, this volume was reduced to 1.8 billion gallons per year by 1994 (King County 1995b).

## 3.4 Characteristics of Stressors

Four principal types of stressors have been identified that affect the study area. They are toxic chemicals, physical disturbance, changes in water quality parameters, and microbial contamination.

### 3.4.1 Toxic Chemicals

Chemicals entering the waterbody may be toxic to aquatic life, wildlife, and people-affecting their survival, growth, and reproduction. Potentially toxic chemicals mainly include: polynuclear aromatic hydrocarbons (PAHs), from fuel constituents; polychlorinated biphenyls (PCBs), from transformer coolants; organic solvents, phthalates, phenolics, and metals (mercury, arsenic, lead, copper, tin, cadmium, zinc) from industry. Chemicals enter the study area from both point sources such as permitted industrial discharges, treatment plants, storm water, CSOs, accidental spills and leaks, and non-point sources including runoff, atmospheric deposition and groundwater. Nutrients and pesticides entering the upper watershed decline in the lower river and bay and are not believed to exist at stressing levels.

Intensive surveys of sediments conducted by Metro (Romberg et al. 1984), the U.S. Environmental Protection Agency (U.S. EPA 1988, 1993), the State of Washington (WSDOE 1996), and others have reported that sediments throughout much of the Duwamish River and along the Seattle waterfront are contaminated by both metals and organic chemicals. Metals of particular concern include arsenic, mercury, lead, copper, tin, cadmium, and zinc. Organic compounds of concern include PAHs, PCBs, phthalates, solvents (chloroform, trichloroethane, 1,4-dichlorobenzene), benzoic acid, and phenol. Also of concern is tributyltin.

In the Duwamish River and Elliott Bay, 25 areas have significantly elevated concentrations that exceed WSDOE's Sediment Management Standards for toxic chemicals and are included in a Contaminated Sediment Site List (WSDOE 1996). These areas of deposition are shown in Figure 3-3 and Figure 3-4. In the Duwamish River and along the Seattle waterfront PAHs in the sediments can reach 10 ppm dry weight. PCBs often reach 0.3 ppm dry weight.

**Figure 3-2. Combined Sewer Overflow Locations in the Seattle Metropolitan Area**

# Combined Sewer Overflow (CSO) Map

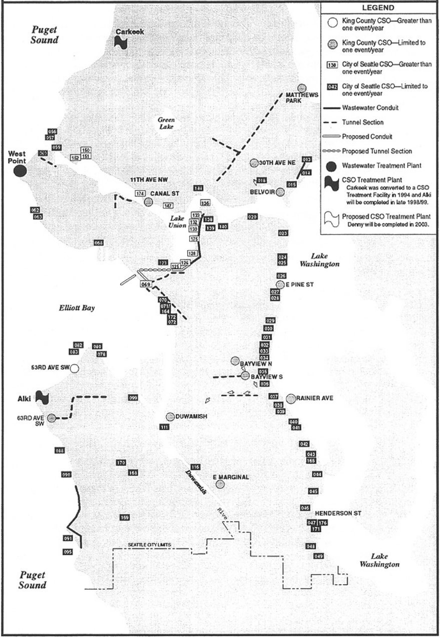
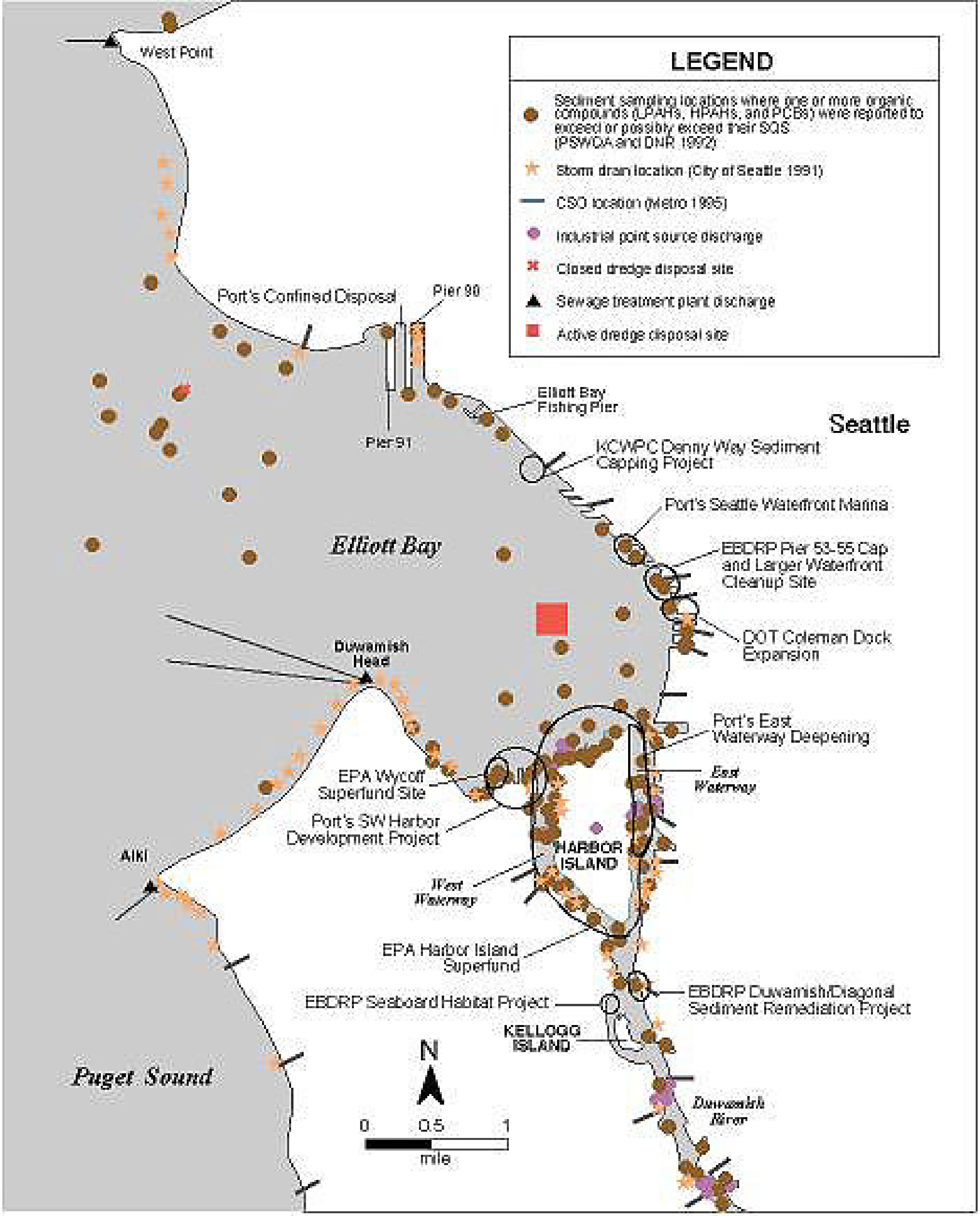


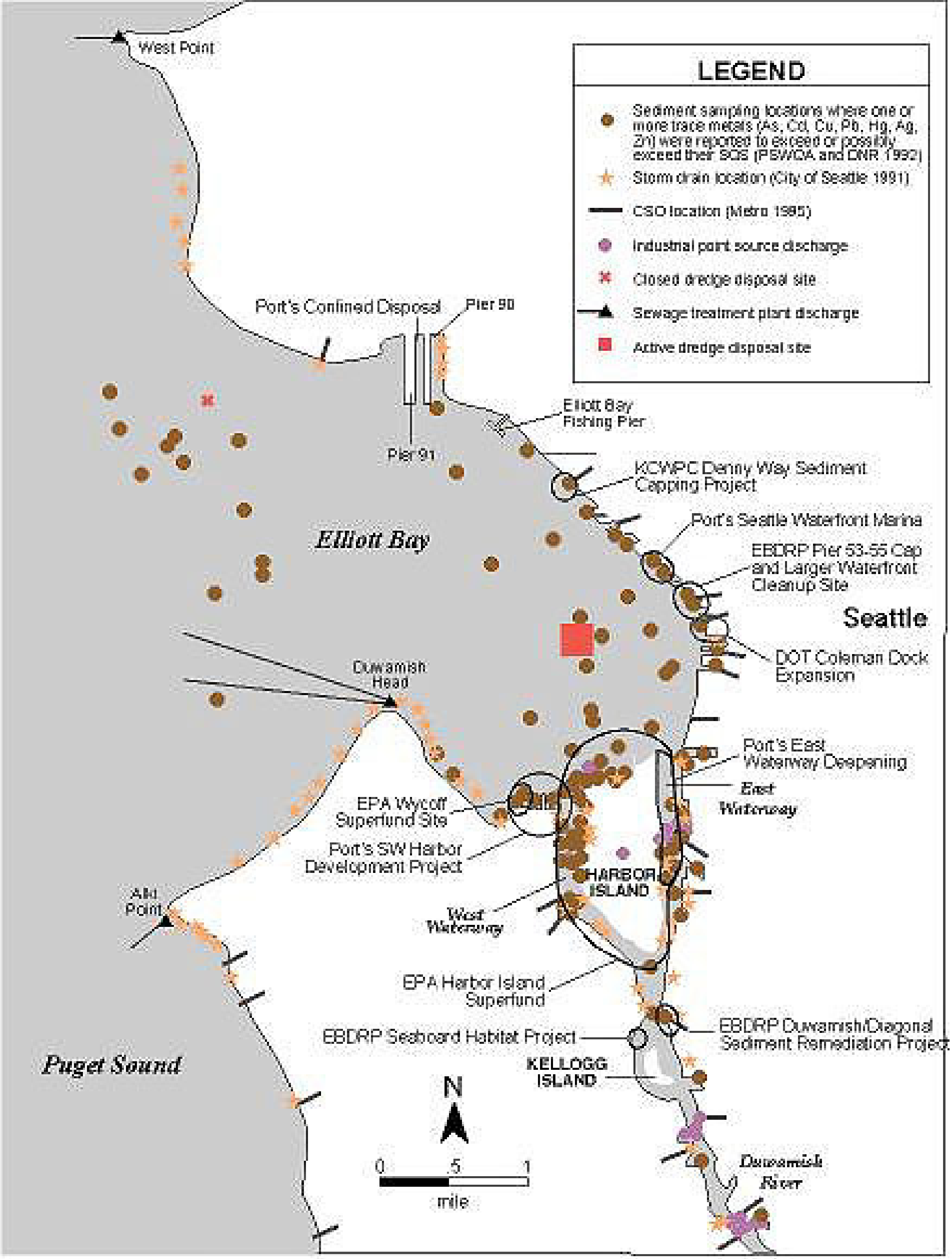



**Figure 3-2.**
**Combined Sewer Overflow Locations in the Seattle Metropolitan Area**




King Co. Problem Formulation/55-1521-23(07) 2/98

**Figure 3-3.**
**Sediment Sampling Locations Where One or More Organic Compounds (PAHs and PCBs) Exceed the State Sediment Standards**




King Co Problem Formulation\55-1521-27(6) 2/99

**Figure 3-4.**
**Sediment Sampling Locations Where One or More Metals (As, Cd, Cu, Pb, Hg, Ag, Zn) Exceed the State Sediment Standards**

CSOs discharge varying amounts of inorganic and organic chemicals during overflows. Stuart and Cardwell (1987) found seven metals and 20 organic chemicals or chemical groups (12 PAHs, five phthalates, chloroform, trichloroethane, and TE-chloroethane). In King County's Water Quality Assessment (1995), eight metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc) and four organic chemicals (benzoic acid, total PAHs, butylbenzyl phthalate, bis(2-ethylhexyl)phthalate) were considered as constituents of potential concern (COPCs).

Specific information on the distribution and extent of toxic chemicals found in sediments below CSOs are analyzed in studies conducted at Denny Way by Metro (Romberg et al. 1984, 1987) and King County (1995a, 1996a). These data suggest that chemicals discharged from CSOs are adsorbed to sediment particles that settle to the bottom at varying distances from the end of the pipe depending on particle size and oceanographic conditions. The area of deposition is known as the footprint and can vary in size from 1,000 to 5,000 $m^2$.

### 3.4.2 Physical Disturbance

Physical disturbance includes direct habitat destruction, such as dredging or other construction-related activities, changes in flow patterns, and increased sedimentation. Erosion and sedimentation are related to event-specific flow, the bathymetry of the channel into which the runoff or discharge occurs, and the particle size of sediments present in the bed or added to the flow by resuspension or the discharge.

Physical disturbance can result in changes in physical, chemical, and biological conditions that affect the survival, growth, and reproduction of a wide variety of organisms, both plants and animals. Benthic communities may be particularly vulnerable. Impacts from physical disturbance may be temporary or permanent. Dredging and construction impacts have the tendency to be longer-term while changes in flow or sedimentation result in impacts that are temporary and often seasonal. Resuspension of sediments during erosion events can result in the re-release of chemicals into the water column.

### 3.4.3 Changes in Water Quality Parameters

Freshwater runoff and CSO discharges can lower the salinity of receiving waters. CSOs also have the potential to affect dissolved oxygen (DO) concentration and pH if their effluents are high in nutrients and organic materials. Additionally, CSOs discharges may be warmer than the receiving waterbody. Altered salinity, DO, pH and temperature regimes have the potential to affect most aquatic life.

### 3.4.4 Microbial Contaminants

Microbial contaminants enter the upper watershed in surface runoff from agricultural areas and in groundwater contaminated by failed septic systems. CSOs are the primary source of untreated domestic wastewaters in the lower river and bay. Microbial contaminants of most concern are human pathogens including protozoa, bacteria, viruses, and possibly helminths (tapeworm, round worms). Microbial contaminants persist for varying lengths of time in water, sediments, and shellfish and mainly affect people.

Relatively little information is available that addresses the nature and extent of microbial contaminants other than coliform bacteria in shellfish from the Duwamish River and Elliott Bay. Munger (1983) determined that pathogenic bacteria including Mycobacteria, Salmonellae, and Yersiniae regularly occur in King County sewage sludge. In microbiologic surveys conducted by Heyward et al. (1977), fecal coliform levels were found to be 77 times higher in butterclams than in the water from King County beaches near the County's wastewater treatment plants. No salmonellae or enteric viruses were isolated from the clams.

## 3.5 Ecological Effects of Stressors

Although four types of stressors have been identified as having an impact on the study area, most available information focuses on toxic chemicals.

Chemicals found in sediments in the Duwamish River and Elliott Bay appear to be bioaccumulated by fish, shellfish, birds, and mammals (Romberg et al. 1984; U.S. EPA 1988, Johnson et al. 1994, O'Neil et al. 1995). The dominant contaminants or their metabolites occurring in fish tissues or bile have included mercury, phthalates, PAHs, and PCBs. Recent studies in the Duwamish River and Elliott Bay have documented a steady decline in mercury and PCBs in both salmon and bottomfish (U.S. EPA 1988, O'Neil et al. 1995). Data for shellfish (crabs and clams) indicate that metals (arsenic, mercury, lead and copper) and organics (PAHs, PCBs and pesticides) were generally accumulated at low levels (Romberg et al. 1984, PTI and Tetra Tech 1988).

A few studies have been conducted on the uptake of chemical contaminants by waterbirds and marine mammals that frequent the study area (Oakley 1976, Riley et al. 1983, Speich et al. 1992, Calambokidis 1985, 1991). Researchers have found that PCBs and DDT are accumulated in eggs of great blue heron, glaucous-winged gulls, and pigeon guillemots from the Seattle area. While the levels of residues in eggs are thought to be high enough to cause some eggshell thinning, they are not high enough to cause impairment of reproduction (Speich et al. 1992). Chlorinated hydrocarbons including PCBs have been found in harbor seals in Puget Sound, but have declined significantly since the 1970s. Present levels are believed to be below those that can cause birth effects.

Sediments from the more industrialized areas of the Duwamish River (e.g., East and West Waterways) and from below CSOs in the Duwamish River have caused significant mortality to sediment dwelling organisms (e.g., amphipod, polychaete worm, and echinoderm larvae) in sediment bioassays (U.S. EPA 1988, Shuman 1997 personal communication). Significant depressions in abundances of major taxa (polychaeta, crustacea, pelecypoda, and gastropoda) comprising benthic infauna communities have occurred in the Duwamish River (i.e., West Waterway, Harbor Island, and in Elliott Bay at the Denny Way CSO) (Armstrong et al. 1980, 1981, PTI and Tetra Tech 1988).

The National Marine Fisheries Service (Johnson et al. 1994) has demonstrated that elevated concentrations of PAHs and PCBs occur in bile as metabolites in bottomfish from the Duwamish River. Salmon collected from the Green-Duwamish River showed elevated levels of enzymes in liver that are known to detoxify toxic chemicals as well as early indications of genetic damage (Varanasi et al. 1993, Casillas et al. 1993). These fish also showed increased mortality, reduced growth, and diminished immune response. Johnson et al. (1993) determined that English sole from urban areas of Puget Sound suffered various types of reproductive impairment. Malins et al. (1984,1985) and others (Krahn et al. 1987; Meyers et al. 1987, 1992, 1994) found that the prevalence of liver disease in English sole increased with urbanization, with the highest prevalence in fish from the Duwamish River. Meyers et al. (1995) suggested that the threshold level for liver disease is 0.5 to 2.0 ppm total PAH in the sediments.

## 3.6 Human Exposure to Chemical Stressors

For purposes of this assessment, it is assumed that exposure to toxic chemicals will result from ingestion of contaminated fish, shellfish, and possibly seaweed, or absorption through the skin upon direct contact from working on the water. It is possible that exposure to contaminated sediments could also result from recreational pursuits such as windsurfing or SCUBA diving. Intake of chemicals by swallowing water when engaged in these activities is also possible.

Relatively few assessments of risk to humans from ingestion of chemically contaminated food collected in the Duwamish River or Elliott Bay have been conducted. Metro's Toxicant Pretreatment Planning Study conducted in Elliott Bay (Romberg et al. 1984) determined that while PCBs, DDT, mercury, lead, and cadmium were frequently detected in edible fish and shellfish tissues, the concentrations were substantially lower than FDA criteria. More recently, Pastorok et al. (1986) indicated that the lifetime risk of liver cancer from eating PCB-contaminated bottom fish (English sole) would be about 12 to 33 times higher for the Duwamish River and Elliott Bay than from Carr Inlet, a reference area in south Puget Sound. This study also estimated cancer risks from eating PAH-contaminated shellfish from Eagle Harbor and from eating bottomfish from Commencement Bay, but did not estimate risks associated with bacteria, viruses, or paralytic shellfish poisoning.

Landolt et al. (1987) conducted a study over a two-year period and determined that arsenic and PCBs were the only chemical contaminants found in recreationally caught fish from the urban bays of Puget Sound that were in high enough concentrations to indicate a potential for excess cancer risk when tested by a conventional risk assessment model. Highest levels of arsenic were encountered in fish from Commencement Bay, Sinclair Inlet, and Edmonds. Intermediate levels were encountered in Elliott Bay while lowest levels were found in Port Orchard, Port Madison, and Port Jefferson. Highest PCBs were found in fish from Port Orchard, Sinclair Inlet, and Edmonds. Fish from Elliott Bay were intermediate in PCB concentration while the lowest concentrations were found in fish from Port Madison and Commencement Bay.

Landolt et al. (1987) also determined that the susceptible population consisted of both shoreside and boating anglers and their families. Shoreside anglers were primarily male (57 percent) and Caucasian (68 percent). Fewer shoreside anglers were Asian American (21 percent) or African American (8 percent). Boating anglers were mostly male (69 percent) and Caucasian (86 percent) with fewer participating Asian Americans (8 percent) and African Americans (4 percent). Fishing occurred mainly on weekends during the summer. Commonly caught species were Chinook salmon, Coho salmon, walleye pollock, Pacific cod, and lingcod. Most fisherman consumed fillets, and frying and barbecuing were the most common methods of preparation. Cooking reduced PCB levels by 50 to 90 percent.

An earlier seafood and consumption survey conducted in Elliott Bay by McCallum et al. (1985) indicated that most shoreside fishers were seeking bottom fish and crabs. Sablefish, shiner perch, walleye pollock, Pacific cod, flatfish, and rockfish were the most commonly caught fish while red rock crab was the only crab species caught. Most fish were caught at night in winter months (December to February). Most fishers were male (86 percent) and Caucasian (50 percent). A total of 29 percent were Asian American and 18 percent were African American. Frying was the most popular method (66 percent) of preparation followed by baking (17 percent) and other methods (17 percent).

Tetra Tech (1988) determined that public health risks associated with consumption of chemically contaminated seafood from Puget Sound were primarily attributable to PCBs and arsenic concentrations in fish. The potential cumulative health risks (primarily carcinogenic) were estimated to be $10^{-4}$, or one case in 10,000 for average exposure conditions and $10^{-3}$, or one in 1,000 for high exposure conditions. These conditions occurred in specific locations in Puget Sound (Commencement Bay, Elliott Bay, Manchester, Sinclair Inlet). Exclusive of the contribution of PCBs, the risks are within the generally acceptable range of $10^{-6}$, or one in 1,000,000 to $10^{-5}$, or one in 100,000. Chemical data used in risk predictions were derived from numerous Puget Sound data sources. The estimated consumption rate for fish (12.3 g/day) for the general population was based in part on the studies conducted by McCallum et al. (1985) and Landolt et al. (1987) described above. Consumption rates for shellfish (1.1 g/day) and seaweed (0.006 g/day) for the general population were based on local marketing information. Higher consumption rates for ethnic minorities were estimated to be 95.1 g/day for fish, 21.5 g/day for shellfish, and 4.1 g/day for seaweed.

More recently, the Tulalip and Squaxin Island Tribes (Toy et al. 1996) collected information on consumption habits, rates, and patterns of participating Puget Sound Indian Tribes. The data describe consumption of fish and shellfish by different age groups, how the food was prepared, and where the fish and shellfish were collected.

In the Tulalip Tribe, the median total consumption rate was 0.8 g/kg/day (mean = 1.2) for men and 0.52 g/kg/day (mean = 0.8) for women. In the Squaxin Island Tribe, the median fish consumption rate for men was 0.8 g/kg/day (mean = 1.0) and 0.4 g/kg/day (mean = 0.9) for women.

The rates unadjusted for body weight for the Tulalip Tribe were 63.0 g/day for men and 40.0 g/day for women. For the Squaxin Island Tribe, the unadjusted rates were 66.0 g/day for men and 25.0 g/day for women.

The median consumption rate for children age 0 to 5 was 0.1 g/kg/day (mean=0.4). The median rate for Tulalip children was 0.03 g/kg/day and 0.5 for Squaxin Island children.

In both tribes, preparation of fish and shellfish by baking, boiling, broiling, roasting, and poaching was more frequent than preparation by canning, frying, eating raw, smoking or drying. The fish and shellfish consumed by both tribes were caught in Puget Sound, although the sources varied between tribes.

No known data link specific diseases of humans to microbial contaminants occurring in the Duwamish River or Elliott Bay. An excellent review of microbiological constituents of potential health concern is found in a recently conducted risk assessment for Wollongong, NSW, Australia by the Sydney Water Board (Parametrix 1991).

## 3.7 Human Exposure to Microbial Stressors

The potential pathways for exposure to microbial contaminants are essentially the same as for exposure to toxic chemicals. Of particular concern is exposure from incidental ingestion of water during recreational activities and ingestion of shellfish. The following topics are described in the sections that follow:

- Potential public health impacts from microorganisms in CSO discharges
- Levels of protozoa and viruses in sewage, CSOs and stormwaters
- Epidemiological studies linking contaminated recreational waters to health risks
- Outbreak data linking contaminated shellfish to health risks

### 3.7.1 Potential Public Health Impacts from Microorganisms in CSO Discharges

Sewage and stormwaters can carry many different microorganisms that have the potential for causing harm to the environment and to people. Discharge of these wastewaters to coastal environments may effect people either through recreational exposure or through accumulation through the foodchain. In general, contamination of the marine environment can be caused by human waste disposal through septic tanks, inadequately disinfected sewage effluents, outfalls and storm waters, in addition to CSOs.

During 1996, nearly 3,700 beach closings and advisories were issued at U.S. ocean, bay and Great Lake beaches (NRDC 1998). The detection of excessive levels of bacteria caused 83 percent of the closings. While historically the focus of monitoring has been on enteric diseases such as those causing diarrhea, also of concern are infections of the skin, wounds, respiratory and genital tracts, eyes, and ears (Alexander et al. 1992; Ballarajan et al. 1991; Corbett et al. 1993; Dadswell 1993, 1986; Fleisher et al. 1996). Transmission of disease has been documented from individuals swimming, wind surfing, and even boating in or on polluted waters (Fewtrell et al. 1992, Popvich and Bondarenko 1989). Concern for such transmission has been heightened with the emergence of new pathogens (e.g. *E. coli* O157 H7 and *Cryptosporidium*), antibiotic resistant strains, and a more susceptible population (due to more elderly, AIDS, and immune suppressant medical treatments).

Microbiological contamination of surface water may also result in disease through consumption of contaminated shellfish. In the U.S., fish and shellfish are still a major source of foodborne disease associated with microbial contamination (CDC 1996). Many studies have linked consumption of raw or partially cooked shellfish with virus originating from human sewage (McDonnell et al. 1997, Luthi et al. 1996, Le Guyader et al. 1996, CDC 1997). Outbreaks have occurred from the consumption of baked, broiled, steamed, and fried shellfish (Lipp and Rose 1997) due to the heat resistance of these viruses. During the 1960s in the United States, hepatitis A was the predominant disease reported associated with consumption of raw shellfish but today acute gastroenteritis is most prevalent (Melnick 1995, Le Guyader et al. 1996). Many of the cases of gastroenteritis are caused by small round-structured viruses such as Norwalk and Norwalk-like viruses (Ahmed 1992, Le Guyader et al. 1996).

Naturally-occurring *Vibrio parahaemolyticus* bacteria are associated with shellfish disease but will not be addressed here because they are endemic in coastal waters.

Public health and safety are tied to the understanding of sources of pollution, so that prevention and remediation can be accomplished, and timely (preferably advance) public information can be made available. The keystone of any effort is the measurement of water quality and protection of these waters from pollution.

Four types of microorganisms in sewage are generally associated with potential human health risks: bacteria, viruses, helminths, and protozoa. The bacteria such as *Salmonella* sp., *Yersinia enterocolitica, Shigellae* sp., *Escherichia coli, Clostridrium perfringens, Staphylococcus* sp., *Enterococcus* sp., *Campylobacter jejuni* are generally considered less of a risk compared to viruses and protozoa due to their comparatively poor survival in marine waters and the higher doses needed to initiate infections. Helminths produce very large eggs that settle with other solids, therefore the risks associated with either the foodchain or recreational exposure in marine waters are low compared to the other groups of microorganisms. The major risks appear to be associated with the viruses and protozoa.

***Enteric Viruses.*** There are several hundred enteric viruses that are possibly important agents of waterborne disease. However, there is limited information regarding the incidence of viral infections in the United States populations as well as throughout the world, and the role of contaminated water in acquiring these. Bennett et al. (1987) reported 20 million cases of enteric viral infections and 2010 deaths per year.

Adenoviruses, which may be transmitted by the respiratory route as well, account for 10 million cases and 1,000 deaths per year, making this the most significant virus affecting U.S. populations. Rotavirus cases were documented as the second most common virus infection and are particularly of concern for infants.

Diarrhea has been one of the risks associated with many of the enteric viruses such as Norwalk virus, but more serious chronic diseases have now been associated with viral infections. These risks need to be better defined. Studies have now reported for example, that Coxsackie B virus is associated with myocarditis (Klingel et al. 1992). This could be extremely significant given that 41 percent of all deaths in the elderly are associated with diseases of the heart. In recent studies, enteroviral RNA was detected in endomyocardial biopsies in 32 percent of the patients with dilated cardiomyopathy and 33 percent of patients with clinical myocarditis (Kiode et al. 1992). In addition, there is emerging evidence that Coxsackie B virus is also associated with insulin-dependent diabetes (IDD) and this infection may contribute to an increase of 0.0079 percent of IDD (Wagenknecht et al. 1991).

***Giardia and the Enteric Protozoa.*** *Giardia* is a common waterborne enteric protozoan found in the fecal wastes of animals and humans. There are an estimated 20,000 cases in the U.S. of giardiasis per year (Bennett et al. 1987). Symptoms associated with giardiasis include diarrhea with loose, foul-smelling stools that are greasy, frothy or bulky; abdominal cramps, bloating, nausea, decreased appetite; malaise and weight loss in the majority of patients (Adam 1991). *Giardia* infections have an incubation period of 3 to 25 days with a median of seven to ten days with the duration of disease ranging from one week to four months (Benenson 1995). Untreated individuals are sick on average about one week, and their infections last about six weeks. Immunoglobulin antibody (IgA) deficiency is common in populations (10 percent) and may increase the risk of chronic diarrhea and maladsorption. Other chronic conditions have been reported including urticaria and reactive arthritis (Adam 1991). Chronic infections may last for a mean of 1.9 years, however, up to 58 percent may exhibit symptoms for 3.3 years.

*Cryptosporidium* was first diagnosed in humans in 1976. Since that time, it has been well recognized as a cause of diarrheal illness (Dubey et al. 1990). Reported incidence of *Cryptosporidium* infections in the population range from 0.6 to 20 percent depending on the geographic locale. There is a greater prevalence in populations in Asia, Australia, Africa, and South America. *Cryptosporidium* is the most significant cause of drinking water and recreational waterborne disease in the U.S. today. The occurrence in surface waters had been reported in 4 to 100 percent of the samples examined at levels between 0.1 to 10,000 oocysts per 100 Liters depending on the impact from sewage and animals (Lisle and Rose 1995). *Cryptosporidium* is of particular concern for three reasons. The oocyst is extremely resistant to disinfection and cannot be killed with routine water disinfection procedures. The disease is not treatable and the risk of mortality ranges between 50 and 60 percent in the immunocompromised populations (Rose 1997).

Both of the enteric protozoa *Cryptosporidium* and *Giardia* are important causes of diarrhea acquired through swimming (shellfish acquired disease has not been documented as it has for the viruses). During 1991 and 1992, six (55 percent) of the 11 outbreaks associated with recreational water with identifiable etiological agents were attributed to *Giardia lamblia* (4 or 67 percent) or *Cryptosporidium parvum* (2 or 33 percent) (Moore et al. 1993). In comparison, during 1993 and 1994, ten (71.4 percent) of the 14 outbreaks of swimming-associated (unintentional ingestion) gastroenteritis were caused by either *C. parvum* (6 or 60 percent) or *G. lamblia* (4 or 40 percent) (CDC 1996). The four recreational outbreaks of *G. lamblia* were associated with two lakes, a river, and a community swimming/wading pool. Swimming and other recreational activities, where unintentional ingestion of water occur, are known to increase the risk of gastrointestinal illness, even in non-outbreak settings.

### 3.7.2 Levels of Protozoa and Viruses in Sewage, CSOs and Stormwaters

Only a few studies have examined the occurrence of the enteric protozoa, *Cryptosporidium* and *Giardia* in wastewater. *Cryptosporidium* levels in untreated wastewater vary throughout the year and are usually lower than enteroviruses (ranging from 100 to 1,500 oocysts per 100L). *Giardia* on the other hand is found to be present in sewage on a continual basis and is found at levels greater than the enteroviruses, on average between 3,900 and 49,000 cysts/100L (Table 3-1).

**Table 3-1. Levels of Pathogenic and Indicator Microorganisms Reported in Untreated Wastewater**

| Location | TC CFU/100Ml | FC CFU/ 100mL | Entero-virus PFU/100L | Crypto-sporidium Oocysts /100L | *Giardia* Cysts /100L | Reference |
|---|---|---|---|---|---|---|
| Occoquan, Virginia | $2.4x10^7$ | $9x10^5$ | 1,085 | 1,484 | $4.9x10^4$ | Rose et al. (1996a) |
| St. Petersburg, Florida | $8.2x10^7$ | $2.2x10^7$ | 1,000 | 1,500 | $6.9x10^3$ | Rose et al. (1996) |
| South Africa | $2.46\ x10^5$ | NA | 71,000 | NA | NA | Grabow et al. (1978) |
| Tampa, Florida | NA | NA | 7,000 | 30 | 3,900 | City of Tampa (1990) |
| Los Angeles, California | NA | NA | 5,493<br>41,344<br>19,638 | NA | NA | Yanko (1993) |
| San Diego, California | NA | NA | 2,200 | 200 | $3.25x10^4$ | Danielson et al. (1996) |
| Denver, Colorado | $8x10^5$ | 40,000 | NR | 100 | 200 | Lauer (1991) |

TC = total coliforms
FC = fecal coliform
CFU = colony forming units
PFU = plague forming units

Only one study reported on levels of a bacterial pathogen: 2.2 CFU-MPN/100mL of *Salmonella* (or 2,200/100L) (Danielson et al. 1996)

Virus concentrations reported in sewage vary greatly and reflect the variation in infection in the population excreting the agent, the season of the year (outbreaks of viral disease are often seasonal), methods used for their recovery and detection. Enteroviruses tend to be prevalent in the spring and rotaviruses in the winter (Gerba et al. 1985). In untreated domestic wastewater, levels as high as 492,000 viral units per liter have been detected and in secondary effluent following disinfection, levels were reduced to between 2 and 7,150 viral units per liter (Irving 1982).

The effects of CSOs on surface water protozoa concentrations have only recently been studied. In Pennsylvania, the Saw Mill Run Stream receives 26 CSOs, is approximately 19 km long, and terminates in the Ohio River near the confluence of the Allegheny and Monongehela Rivers. The stream's watershed is about 51 $km^2$ and travels through residential, commercial, industrial, and forested areas. Studies in Pennsylvania noted *Cryptosporidium* and *Giardia* in urban streams during dry weather conditions at concentrations ranging from 5 to 105 oocysts/100L and 13 to 6,579 cysts/100L, respectively. During wet weather conditions, levels of 250 to 40,000 oocysts/100L, and 9,000 to 283,000 cysts/100L, respectively, were observed in waters impacted by CSOs (Gibson et al. 1998).

*Giardia* has been found to be much more common and in higher concentrations than *Cryptosporidium* in many studies. Table 3-2 summarizes the levels of *Giardia* cyst contamination reported in various types of water.

**Table 3-2. Occurrence of *Giardia* in Various Water Types [a]**

| Type of Water | Percent Positive | Concentration (cysts/L) |
|---|---|---|
| Untreated Wastewater | 100 | 642 to 3,375 |
| Activated Sludge Effluent | 83 | 0.14 to 23 |
| Filtered Secondarily Treated Wastewater | 75 | <0.01 to 0.2 |
| Surface Water | 45 | <0.02 to 44 (2.0) |
| Groundwater | 6 | 0.1 to 120 (0.08) |
| Treated Drinking Water | 17 | 0.29 to 64 |
| Combined Sewer Overflows | 100 | 90 to 2,830 |

[a] (Rose et al., 1991, LeChevallier et al. 1991, Norton and LeChevallier 1995, Hancock et al. 1998, Gibson et al. 1998)

Viruses have also been detected in stormwater at levels between 2.6 and 106 plaque forming units (pfu) (pfu is the cultivatible unit for cell culture) per liter (O'Shea and Field 1992). Some of these waters were without direct sewage discharges.

Septic tanks have also been shown to be a source of viral contamination of water and there have been several outbreaks associated with groundwater caused by contamination from septic tanks (Yates and Yates 1988). Virus levels range from 6 to 4370/100L in septic tank effluent and were found in the underlying groundwater at levels of 0.05 to 0.3/100L (Anderson et al. 1991). Other than this single study, concentrations of viruses from septic tanks influencing ground and surface waters have not been reported. However, viruses may travel as far as 1,600 meters in defined studies on viral transport (Yates and Yates 1988).

Transport of viruses in the marine environment has been well documented. Enteroviruses have been isolated in sediments along a Florida bathing beach (Schaiberger et al. 1982). Two of three stations 3.6 km from a sewage outfall were positive for viruses, averaging 2.2 pfu per 100 $cm^3$ of sediment. Viruses were not isolated from the water column and a significant association was demonstrated between the concentrations of viruses and the distance from the outfall. Indicator bacteria and viruses could not be detected in water samples at distances greater than 200 meters from the outfall. Indicator bacteria could not be isolated from sediments at distances greater than 400 meters from the outfall. It has been suggested (Schaiberger et al. 1982, Rao et al. 1984) that viruses may be sequestered in sediments and then transported shoreward. The resuspension of viruses in sediments in deep coastal waters near the outfall pipe would be insignificant due to dilution of the viruses in the large volume of overlying waters. In shallow coastal waters sediments could significantly impact public health by serving as reservoirs for viral contamination of the water column resuspended by currents, storms, boats, swimmers, dredging, etc.

### 3.7.3 Epidemiological Studies Linking Contaminated Recreational Waters to Health Risks

There is a great deal of documentation showing that exposure to wastewater will transmit disease. There also continue to be drinking water outbreaks associated with wastewater contamination (Craun 1986). In addition, recreational waterborne outbreaks are associated with enteric bacteria, viruses, and protozoa (Herwaldt et al. 1991, Moore et al. 1993, Levine and Craun 1990, Craun 1986). Viruses, associated only with human fecal wastes, have led to many disease outbreaks from exposure to recreational waters, with as many as 1,000 people ill. A disease outbreak is normally considered to reach epidemic proportions when one in ten persons in a given population have contracted the disease.

Disease outbreaks associated with recreational exposure to contaminated marine waters generally are not reported. The lack of reported outbreaks may be due to the dilution typically achieved, the salinity of marine waters, or the size of the exposed population. Epidemiological studies have been able to document lower risks associated with human use of contaminated marine waters than with contaminated freshwater (Cabelli et al. 1979).

Cabelli et al. (1992) studied swimmers at beaches in New York, Massachusetts and Louisiana and found an increased 2 in 100 risk of disease at enterococcus levels of 10 cfu/100 ml. Ballarajan et al. (1991) studied marine beaches in England. They reported that 24.2 percent of the individuals using the recreational site reported symptoms of ear infections, sore throat, sore eyes, respiratory disease, and gastrointestinal illness. Risk was shown to increase with an increase in exposure from waders to swimmers to surfer to divers (going from least risk to highest risk for the various water activities). Alexander et al. (1992) likewise found risks associated with using marine waters containing virus levels of 20 to 40 viral units per 100L. Children were found to be at greatest risk displaying symptoms of diarrhea, vomiting, and itching skin. Fewtrell et al. (1992) reported that canoeing on highly polluted waters (fecal coliforms 285 CFU/100mL and 1,984 viruses per 100L) was associated with increased risk of gastrointestinal illness even though there was no direct exposure to the water through full-body contact. This has implications for even recreational boaters.

Acute febrile respiratory illness has also now been documented in bathers using marine water contaminated with sewage (Fleisher et al. 1996) with about 4 to 8 per 100 bathers becoming ill at levels of fecal streptococci between 14 and 158/100mL.

Studies in Santa Monica Bay, California showed increased risks of ear, eye and skin infections to lifeguards. These have been associated with storm drain discharges (Sullivan and Barron, 1989). Additional epidemiological studies of swimmers and non-swimmers at Santa Monica beaches (Haile et al. 1996) showed increased risks to swimmers that swim in front of flowing storm drains relative to people that swim 400 yards away from the same drains. Haile et al. (1996) also determined that the ratio of fecal to total coliforms was the best indicator of health effects.

Recently, Pruss (1998) reviewed the data on the relationship between health effects and exposure to recreational water. Pruss identified 37 studies on the relationship between health effects and exposure to recreational water, 22 of which satisfied her criteria for study acceptability. The studies often identified a significant increase in health risks for swimming in contaminated waters relative to clean waters. The indicator organisms that correlate best with health outcomes were frequently enterococci/fecal streptococci for both marine and freshwater, and *Escherichia coli* for freshwater. In both marine and freshwater, increased risk of gastrointestinal symptoms was reported for water quality values ranging from only a few indicator counts/100 ml to about 30 indicator counts/100ml.

### 3.7.4 Outbreak Data Linking Contaminated Shellfish to Health Risks

Perhaps the best data set on shellfish-associated outbreaks is a 10-year summary of outbreaks in New York (Weingold et al. 1994). The New York City Health Department has an aggressive and active surveillance program using the electron microscope for investigating outbreaks. The data show that 40 percent of all virus outbreaks in New York that were studied by the New York City Health Department were due to contaminated shellfish. The viruses responsible for the outbreaks in greater than 75 percent of the cases studied were identified as Norwalk virus or related viruses (i.e.

caliciviruses, small round structured viruses). These viruses originate only from human fecal wastes and can bioaccumulate in shellfish.

## 3.8 Uncertainty and Limitations of Database

### 3.8.1 Toxic Chemicals

Most available information on toxic chemicals comes from intensive surveys of the study area conducted by Metro, the U.S. EPA, and WSDOE. These studies have addressed the distribution and extent of chemicals in sediments, their bioaccumulation in edible fish and shellfish, and their effects on sediment dwelling aquatic life. A number of other bioeffects studies focusing on both migratory and resident fish have been conducted by the National Marine Fisheries Service and the Puget Sound Water Quality Authority. These data provide historical perspective and are helpful in understanding overall levels of stress from toxic chemicals affecting the study area.

Only a few data are available to address the distribution and extent of chemicals released by CSOs in the study area. These same studies documented toxic effects on sediment dwelling invertebrates (amphipods, polychaetes worm, and echinoderm larvae [sea urchin]) using standard sediment bioassay protocols. Also, some applicable benthic community data were collected from some of the same locations. To date, no local studies have chronicled the potential toxicity effects of CSO discharges on invertebrates or fish inhabiting the water column. However, relevant data from other areas of the country have documented wet weather chemical exposure regimes as being typically brief and highly variable in magnitude (Herricks et al. 1995).

### 3.8.2 Physical Disturbance

Almost no data exist on current levels of physical disturbance either in the study area as a whole or associated with CSO discharges.

### 3.8.3 Changes in Water Quality Parameters

Only anecdotal information is available on the effects of CSO discharge on water quality parameters (salinity, DO, pH, and temperature) of the receiving water. However, information is available on how changes in these water quality parameters may affect the aquatic life of the study area. No information is available on changes in these parameters currently affecting the study area as a whole, regardless of source.

### 3.8.4 Microbial Contamination

Limited information is available on the numbers of fecal coliform bacteria released from CSOs, but there is almost no information on the nature and concentration of bacterial and viral pathogens associated with CSOs effluents. Available information is based on analyses of sludge collected at treatment plants. A significant amount of local data exists on the concentrations of coliform bacteria in edible shellfish, however, there is little information on the concentrations of other bacterial or viral pathogens in shellfish.

### 3.8.5 Human Health Exposure and Potential Health Effects

The 1995 WQA did not include quantitative ecological or human health risk assessments due to the lack of sufficient available data and the degree of uncertainty associated with predictive models. The lack of sufficient available data included information necessary to conduct a baseline exposure assessment and risk characterization for the study area.

Estimates of human health risks associated with exposure to chemicals in the study area based on other investigations (e.g., Pastorok et al. 1986, Landolt et al. 1987, Tetra Tech 1988) are out of date. Chemical concentrations in the water column, sediments, and in seafoods may be different now compared with 10 years ago, and the species included in the subsistence and recreational fish catches as well as human consumption rates will have changed. There also are no known data that link specific diseases of humans to microbial contaminants occurring in the Duwamish River and Elliott Bay.

## 3.9 Selection of Assessment Endpoints

Assessment endpoints are measurable attributes of valued resources that include both an entity (e.g., salmon) and a measurable attribute (e.g., survival). They provide direction for the risk assessment and are the basis for the development of questions, predictions, models, and analyses. Assessment endpoints were developed by the WQA Project Team scientists and consultants with key input from the WQA Stakeholder Committee's Technical Subgroup. The selection of assessment endpoints was based on societal values expressed in the management goal, as well as an evaluation of available information to ensure that the endpoints were ecologically relevant and were susceptible to identified stressors. The Team's identification of an assessment endpoint does not imply that data currently exist in the Duwamish Estuary to quantify proposed attribute changes. Assessment endpoints are only required to support the ability to collect data for quantification.

### 3.9.1 The Assessment Endpoints

Ten endpoints were selected to represent freshwater and estuarine components of the ecosystem and human health concerns. In some cases overlap among assessment endpoints is recognized and endpoints could be combined later in the process. The assessment endpoints selected for the Duwamish River/ Elliott Bay WQA include:

- Survival of juvenile salmonids (outmigrants)
- Survival of resident fish species (e.g., English sole)
- Health of resident fish species (e.g., English sole)
- Survival of polychaetes and amphipods; growth of polychaetes
- Abundance and richness (community structure) of benthic invertebrates
- Survival of spotted sandpipers

- Survival of great blue herons
- Survival and reproduction of bald eagles
- Survival of river otters
- Cancer and non-cancer health effects

### 3.9.2 Assessment Endpoint Description and Rationale

Assessment endpoints were selected based on three criteria:

1. How well they represented the management goal (societal value)
2. How well they sustained ecological integrity in the affected ecosystem (ecological relevance)
3. How likely they were to be exposed to and adversely affected by known stressors (susceptibility)

Each assessment endpoint is described below to highlight its characteristics as they relate to ecological relevance, potential for exposure to known stressors, and societal value.

Proposed measures and how risk will be assessed are also discussed. They also are presented in summary form in Table 3-3. A more detailed account of proposed risk measures may be found in the analysis plan (Appendix A2).

***Fish.*** Salmon survival was selected as an assessment endpoint. Salmon have commercial, recreational, and cultural value and are ecologically significant. The juvenile or outmigrant smolt is recognized as the most sensitive lifestage found within the study area. While several species of salmon (Chinook, Coho, chum, pink) and trout (steelhead, cutthroat, Dolly Varden) use the study area, Chinook and chum salmon demonstrate greater estuarine reliance than the other species. Juvenile Chinook outmigrants are present in the Duwamish Estuary from early April to mid-July. Juvenile chum outmigrants are found in the estuary in significant numbers from early February to mid-July. Juveniles of both species do not immediately go to sea upon entering the estuary but appear to linger over a period of two to three months (Warner and Fritz 1995). Juvenile salmon feed on a variety of epibenthic and infaunal invertebrates during this time. Both salmon species as outmigrants appear to be susceptible to CSO discharges, which occur predominantly over a period extending from October through April.

**Table 3-3. Assessment Endpoints-Ecological Risk**

| Component or Receptor | Assessment Endpoint | Possible Measurement Approach |
|---|---|---|
| Fish | Survival of outmigrants (Chinook, chum) | Modeled toxicity to prey salmon(copepod/daphnid) ba |
| | Survival of resident fish | Modeled toxicity to prey(copepod/daphnid) based on modeled or measured concentrations of chemicals in water column or sediment pore water, with laboratory validation |
| | Health of salmon outmigrants and English sole | Modeled bioeffects (liver disease, DNA adducts, reproductive impairment) based on modeled or measured concentrations of chemicals in sediments, in fish tissues, or in body fluids (bile) |
| Epibenthos | Survival of polychaete and amphipod, or growth | Modeled response/toxicity based on modeled or measured concentrations of chemicals in sediment pore water, with laboratory validation |
| Benthos (infauna) | Community structure, habitat value to aquatic species | Modeled response/toxicity (numbers of genera impacted) based on modeled or measured other concentrations of chemicals in sediment pore water, with field validation employing abundance of individuals and species present |
| Shorebirds | Survival of spotted sandpiper | Modeled response based on modeled or measured concentrations of chemicals in prey (invertebrates) |
| Wading birds | Survival of great blue heron | Modeled response based on modeled or measured concentrations of chemicals in prey (fish) |
| Raptor | Survival and reproduction of bald eagle | Modeled response based on modeled or measured concentrations of chemicals in prey (fish, ducks) |
| Mammals | Survival of river otter | Modeled response based on modeled or measured concentrations of chemicals in prey (fish, crab) |

Estimates of risk will be based on modeled toxicity to salmonid prey (copepod/daphnid) species using modeled or measured concentrations of chemicals or changes in other water quality parameters (DO, salinity, temperature). Estimates of risk based on modeled relationships will be tested (validated) in the laboratory employing *Ceriodaphnia* or sea urchin embryos. Certain invertebrates (e.g., *Ceriodaphnia)* are sufficiently sensitive to chemicals that they can be used as indicators of effects to fish and other invertebrates (Ewell et al. 1986, Suter and Rosen 1986). There are less data for sea urchin embryos, but an extensive study by WSDOE (Parametrix 1994) established their high sensitivity to organic chemicals and metals relative to fish and kelp. Because of the strong correlations known to exist between daphnids and other invertebrates and fish, it is possible to extrapolate from the indicator to other species (Barnthouse et al. 1986, Suter and Rosen 1986, Volmer et al. 1983).

Resident fish survival was also selected as an assessment endpoint. Potential exposure of resident fish to chemicals discharged from CSOs and other sources are essentially year-round. A particular resident fish species was not identified but it was assumed that the proposed assessment approach would be protective of all resident fish species. A number of resident fish species (e.g., English sole, starry flounder) are commercially or recreationally important. Other fish species (e.g., shiner perch, sandlance) are important as prey for commercially or recreationally important species. Estimates of risk for resident fish will be computed using the same approach as for salmon outmigrants above, although a pathway also will be included that assumes exposure from sediment pore water.

Additionally, fish health was selected as an assessment endpoint. Maintaining healthy, reproductively successful fish populations in the study area has significant societal value. Exposure to chemicals has been associated with a variety of health effects in English sole and juvenile salmon in urban areas of Puget Sound including the Duwamish River and Elliott Bay. These include elevated levels of chlorinated and aromatic hydrocarbons in tissues and body fluids (bile), elevated levels of carcinogen metabolizing enzymes, binding of chemical carcinogens to liver DNA, and liver pathology (Malins et al. 1984, 1985; Krahn et al. 1987; Buhler and Williams 1989; Varanasi et al. 1989; Collier and Varanasi 1991; Stein et al. 1992; Meyers et al. 1987, 1992, 1995). These contaminants may be linked to development of liver cancers (Meyers et al. 1990), effects on growth (Casillas et al. 1993, Varanasi et al. 1993), reproductive dysfunction (Johnson et al. 1988, Casillas et al. 1991), and altered immune competence (Arkoosh et al. 1991, Casillas et al. 1993).

Estimates of risk will be based on modeled relationships among concentrations of chemicals (particularly PAHs) in sediments, markers of exposure (fluorescent aromatic compounds [FACs]) in the bile of fish or chemical burdens in other tissues, and potential bioeffects. Measures of bioeffects that could be modeled include liver disease, DNA adduct formation, reproductive impairment, survival of eggs and larvae, and juvenile growth.

Sufficient data probably exist to model the relationships between exposure and bioeffects. NOAA has developed regression relationships among chemical (PAH) concentrations, concentrations of bile FACs, and related bioeffects for both English sole and juvenile Chinook salmon. King County has recently analyzed the sediments below most of the CSOs in the study area. King County with the aid of the Washington Department of Fish and Wildlife and NOAA will analyze bile, tissue chemical burdens, and reproductive hormones in English sole from the study area in an effort to augment the NOAA database.

***Benthos.*** Both epibenthic and infaunal species are recognized as sensitive indicators of chemical and physical impacts. Benthic communities inhabiting sediments in the vicinity of CSOs can be subjected to both chemical and physical stress following discharge events. Chemicals tend to accumulate and persist in depositional areas downstream from CSOs and sedimentation can smother shellfish and other benthos. Altered water and sediment quality may affect the abundance of individuals of a species as well as the numbers of species present. The benthos is an important food resource for commercially and recreationally important salmon and other fish and wildlife, which have significant societal value.

Two endpoints have been included to address potential adverse effects of CSO discharges on benthic organisms. The first endpoint addresses survival of polychaetes and amphipods, and growth of polychaetes. Both polychaetes (small segmented worms) and amphipods (small shrimp-like animals) are common to sediments of the Duwamish River and Elliott Bay.

The second benthic endpoint addresses potential bioeffects on benthic community structure. Some of the more informative yet simplest measures (indices) of benthic community structure include: numbers of individuals (abundance), numbers of species, and abundance of dominant, pollution sensitive, or pollution tolerant species. Values for each of these variables are easily obtained from the list of abundances of the species collected and may be tested statistically. Other more complex indices (e.g., species diversity) often lack biological meaning and are beyond the scope of the present study.

For the first benthic endpoint (survival of polychaetes, growth of polychaetes, survival of amphipods), risk estimates will be computed based on modeled or measured concentrations of chemicals in sediment pore water. Modeled results will be compared to results of recent sediment bioassays conducted below CSOs in both the Duwamish River and in Elliott Bay. For the second benthic endpoint (community structure [numbers of genera affected]), risk will be based on modeled or measured concentrations of chemicals in sediment pore water. These results will be compared to results of benthic community analyses conducted near the mouth of several CSOs, at a reference site in the study area, and at a reference site outside the study area.

***Shorebirds, Wading Birds, Raptors, and Aquatic Mammals.*** Endpoints have been included for shorebirds (e.g., spotted sandpiper), wading birds (e.g., great blue heron), and raptors (e.g., bald eagle). All are present on the Duwamish River and Elliott Bay either seasonally or year-round and all three species have high societal value. Spotted sandpipers are protected by the Migratory Bird Treaty Act. The bald eagle has threatened status in Washington under provisions of the Endangered Species Act of 1973, as amended. The great blue heron is listed as a priority species by the Washington State Department of Wildlife (WSDOW 1991).

It is assumed that any potential adverse effect would occur through contamination of the food supplies for these organisms. Spotted sandpipers are found in the study area from late April through early October (Paulson 1993). They probe and pick the surface sediments for small invertebrates, mainly polychaetes and amphipods. The great blue heron is a year-round resident and is a fish eater (e.g., shiner perch). A heron colony (rookery) is located in nearby West Seattle (Norman 1995). Both spotted sandpiper and great blue heron feed intertidally. The bald eagle consumes both fish (e.g., salmon, and waterfowl, for example, Western grebe). Although eagles feed mainly on fish, waterfowl make up a significant portion of their food during winter months. Both resident and migrant birds inhabit the study area.

River otter was included as a representative aquatic mammal endpoint. A family of river otters lives year-round on Kellogg Island. The river otter is a charismatic species that was once harvested for its fur. Otters feed largely on fish but also will feed on crabs and sometimes mussels or clams.

Risks to spotted sandpiper, great blue heron, bald eagle, and river otter, in terms of chemical doses causing toxicity, will be based on modeled or measured concentrations of chemicals in water, in sediments, and in prey species (diet). Chemical analyses of prey species (intertidal invertebrates, shiner perch, and English sole) have been undertaken by King County in support of risk calculations. Concentrations of chemicals in salmon obtained from the Puget Sound Ambient Monitoring Program database will be used to calculate risks for bald eagle.

***Human Health.*** To address human health risks, assessment endpoints have been included for both cancer and other chronic illnesses and infectious diseases, which are mostly associated with chemical and microbial contaminants ingested in seafood. Chemical contaminants can also be absorbed through the skin from direct contact with water, such as when commercial fishing, or by contact with contaminated sediments during recreational pursuits such as windsurfing or SCUBA diving. Intake of chemicals by swallowing water when swimming appears to be another potential pathway for exposure.

Pathogens found in surface water or edible shellfish, mostly clams or mussels, are also of concern. It is assumed that because sewage discharged from CSOs contains coliform bacteria, the sewage also will contain certain pathogens, including bacteria, viruses and parasites. It also is assumed that shellfish accumulate and retain coliforms and pathogens for some finite period. In this case, a possible endpoint is symptomatic illness, but relatively few data have been found to establish a quantitative relationship between exposure and infection for many of the potential pathogens encountered in sewage wastes. Probability of illness occurring after exposure will focus on those pathogens for which sufficient information exists to determine a minimal infectious dose.

## 3.10 Development of Conceptual Site Model

The results of the problem formulation are used in the development of a conceptual model or models where the preliminary analysis of the stressor sources, release mechanisms, stressor characteristics, receptors, and ecological and human health effects are summarized to define potential exposure and effects scenarios. This broad-based modeling approach provides a framework for the risk assessment and an overview of ecosystem processes. The major goal is the development of a series of working hypotheses about how stressors may affect the study area ecosystem.

### 3.10.1 Conceptual Models of Stressor Effects

The conceptual models in Figure 3-5 through Figure 3-10 address how known or suspected stressors may affect aquatic life, wildlife and people in the Duwamish Estuary and Elliott Bay. Where appropriate, distinction is made between stressors associated with CSOs and stressors associated with all other sources in the study area. “Stressors” from all sources (including CSOs) are grouped together in the models, which are designed to address a “baseline risk.”

The models addressing “CSO risk” include the same endpoints as the models describing “baseline risks.” This is because in our approach to risk assessment, we will first estimate total or baseline risks to the ecosystem, then estimate the risks from just the CSOs. The two sets of models only differ in the sources of stressors and the release mechanisms that are applicable.

Each model also includes an initial evaluation of the importance of exposure pathways or sources of impacts to the affected ecosystem. These will be further evaluated in the course of the risk assessment. Specific measures to evaluate exposure scenarios and potential impacts on endpoint receptors are also shown.

The models show if stressors affect one or more than one endpoint. Some indirect effects on receptors are also depicted. Only assessment endpoints, for which data are readily available or will be generated by this project, are represented in the conceptual models. The conceptual model diagrams will initially address four stressor groups: toxic chemicals; physical disturbance; changes in water quality parameters; and microbial contaminants.

***Toxic Chemicals.*** Toxic chemicals (metals, metalloids, and organics) can affect aquatic life, wildlife, and people. Exposures may be both acute (short-term lethal) and chronic (longer-term sublethal).

These chemicals enter the Duwamish River and Elliott Bay from both point and non-point sources. Examples of non-point sources are agricultural pesticides, atmospheric deposition from automotive and industrial emissions, suburban lawn and garden chemicals, runoff from parking lots, roads, and roofs. Examples of point sources are treatment plant releases, stormwater discharges, CSOs, permitted industrial releases, and spills or leaks.

Chemicals discharged from CSOs originate from only two potential sources: stormwater and untreated sewage. Stormwater conveys chemicals of non-point origin in runoff from parking lots, roads, roofs, and to a lesser extent lawns and gardens. Untreated sewage includes chemicals from both permitted industrial discharges and industrial spills and leaks as well as domestic wastes.

***Physical Disturbance.*** Additional stressors to the Duwamish River and Elliott Bay include physical effects (erosion and sedimentation) that may occur from increased river flow during runoff and from CSO discharge. Each effect is related to event-specific

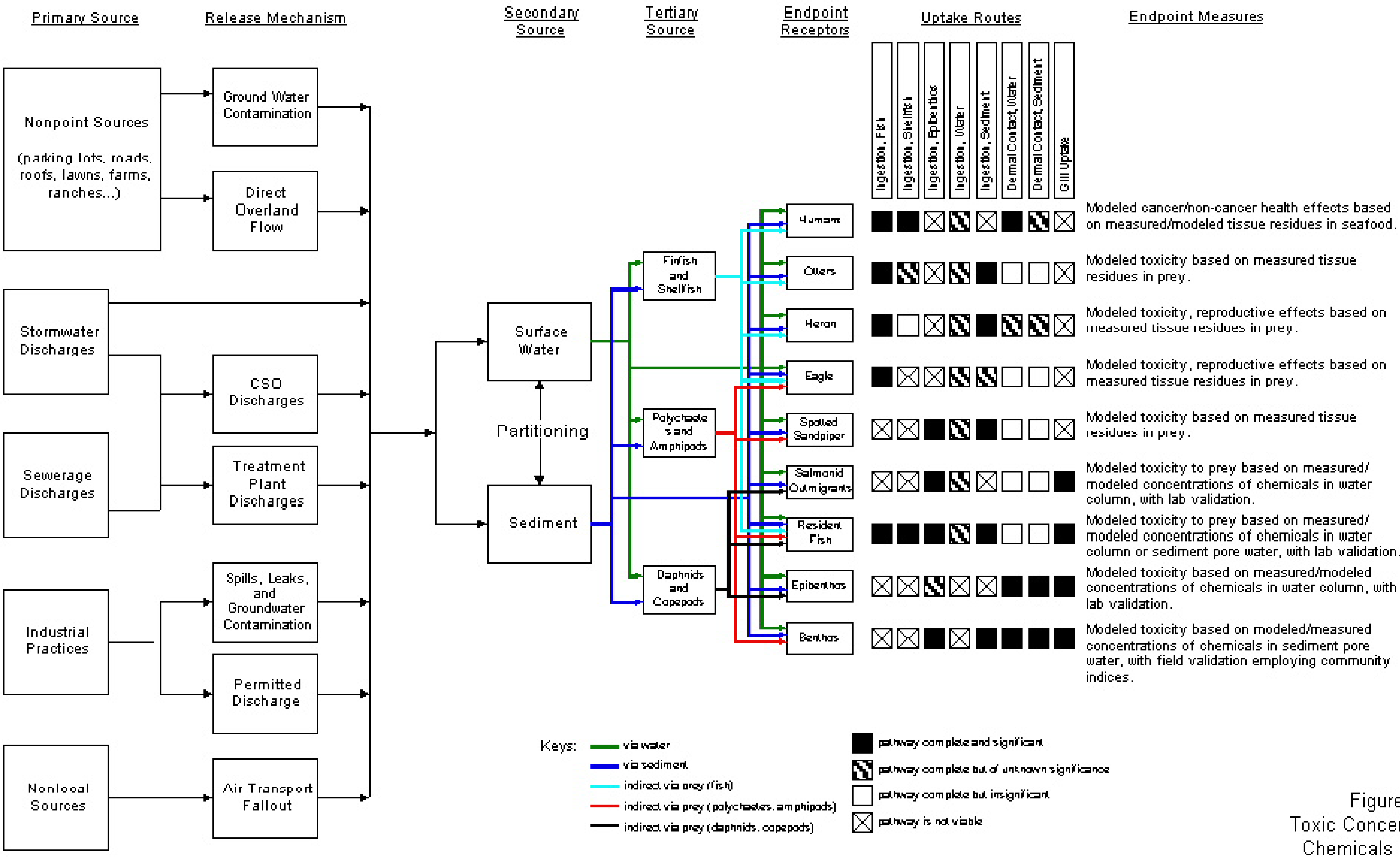



Figure 3-5
Toxic Concentrations of Chemicals Pathway - Baseline Risk

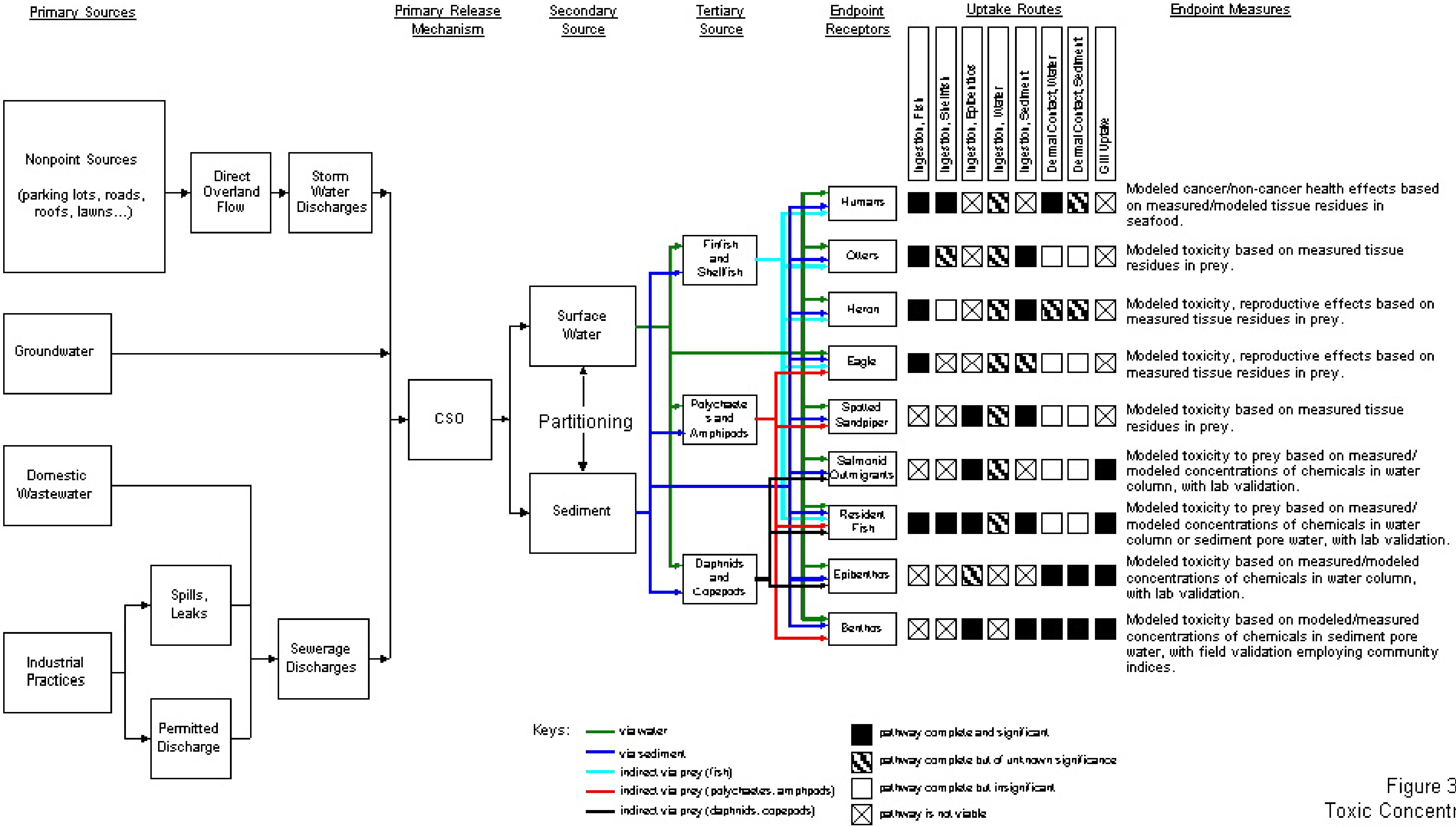



Figure 3-6
Toxic Concentrations of Chemicals Pathway - CSO Risk

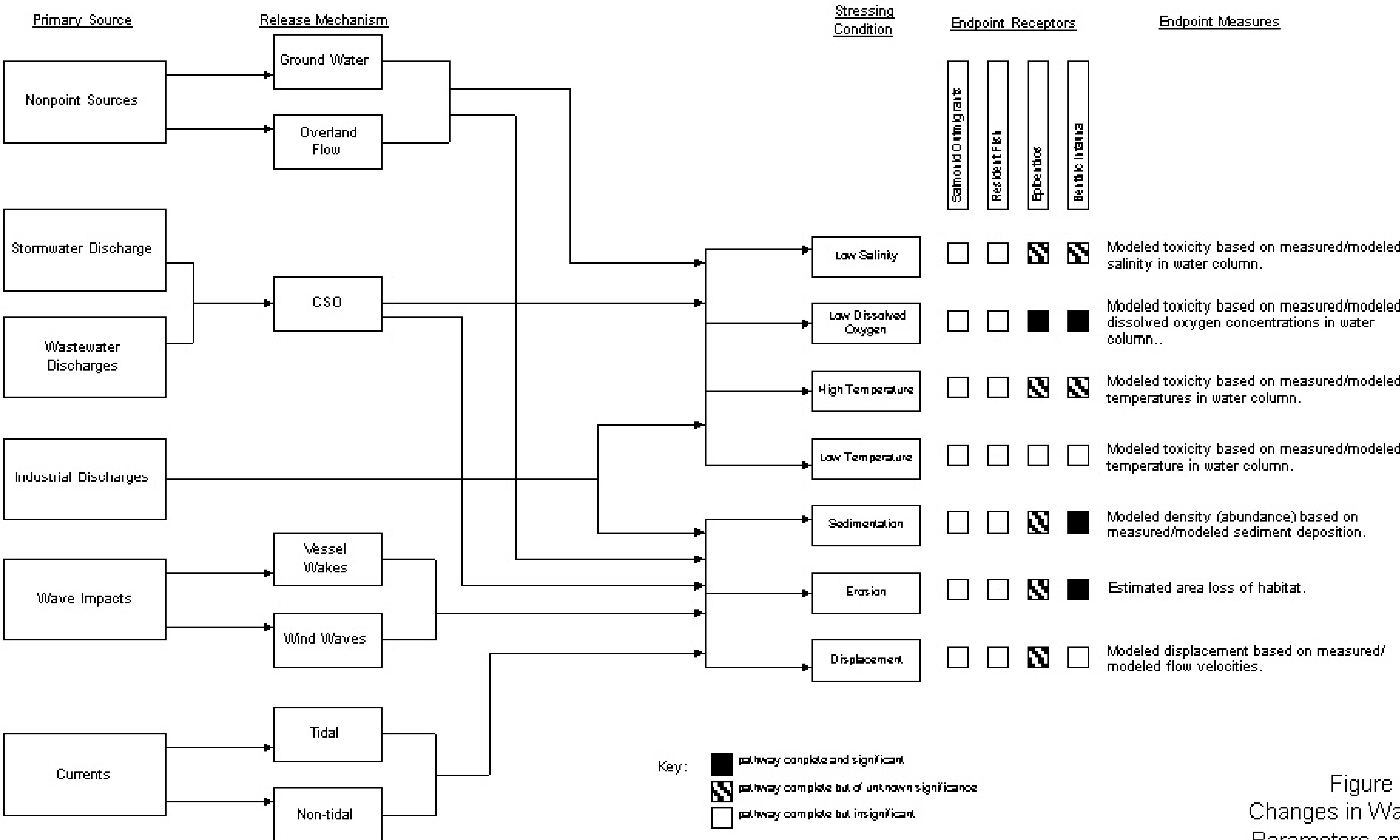



Figure 3-7
Changes in Water Quality Parameters and Physical Disturbances-
Baseline Risk

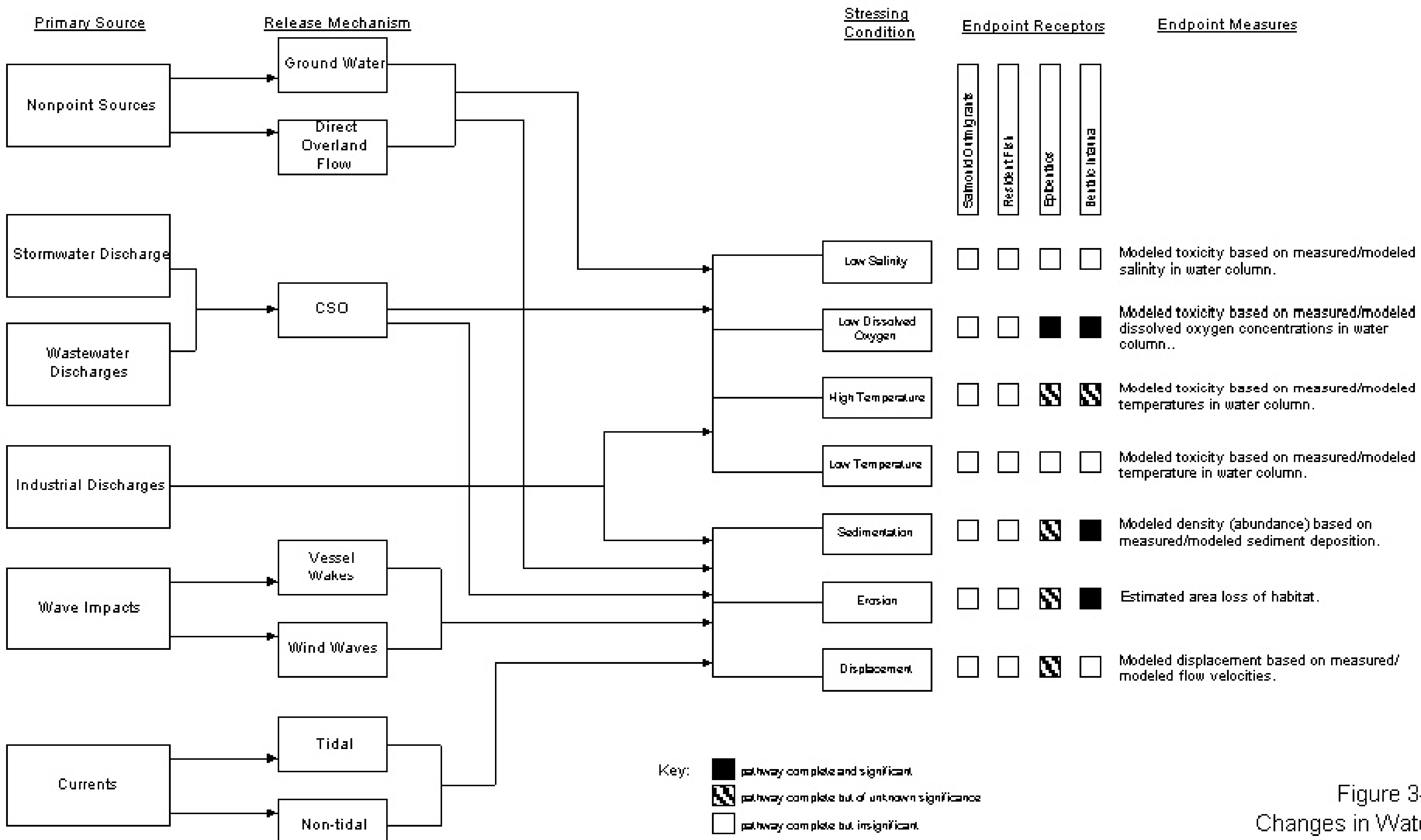



Figure 3-8
Changes in Water Quality Parameters and Physical Disturbances-
CSO Risk

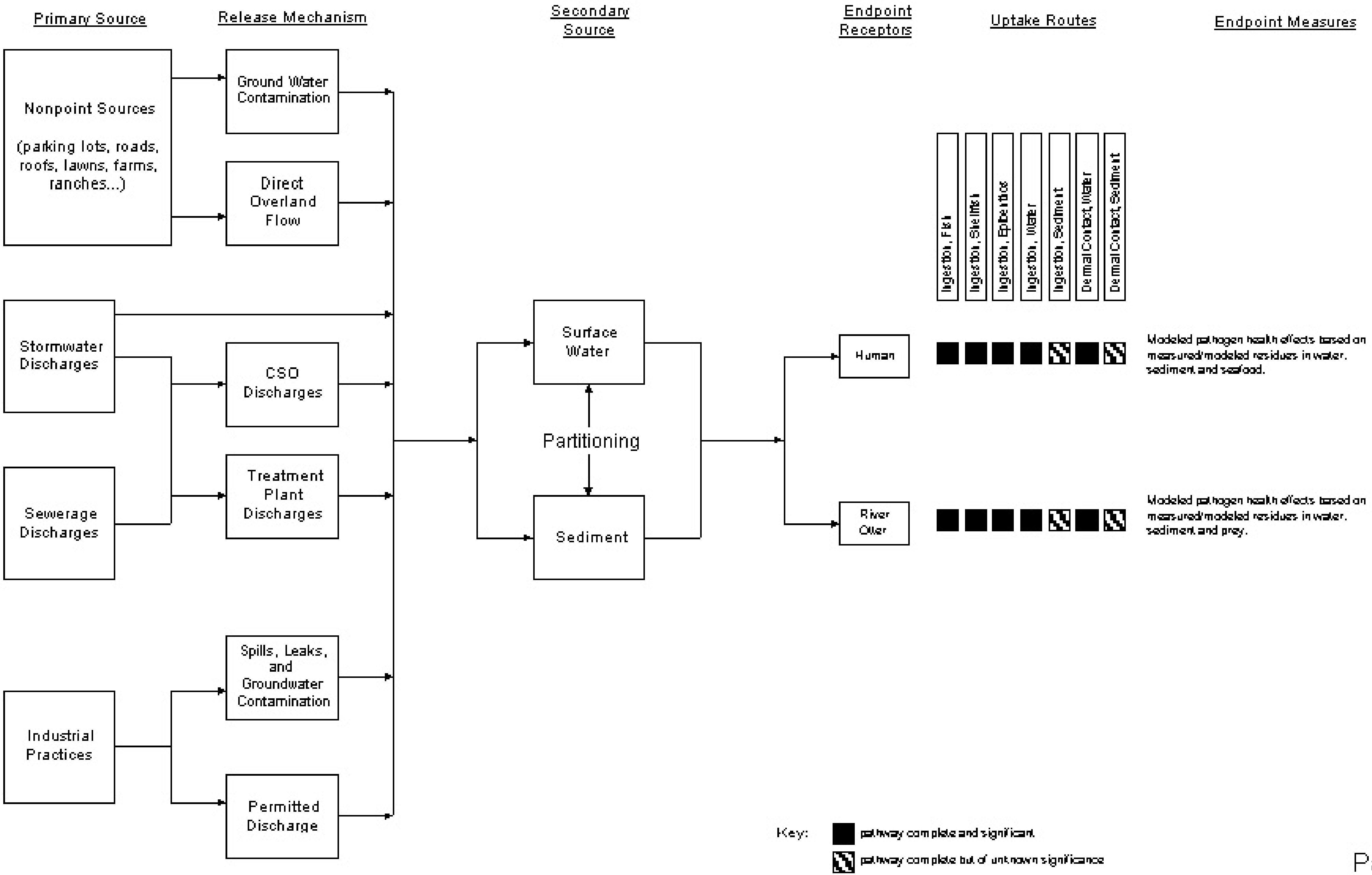



Figure 3-9
Pathogens Pathway - Baseline Risk

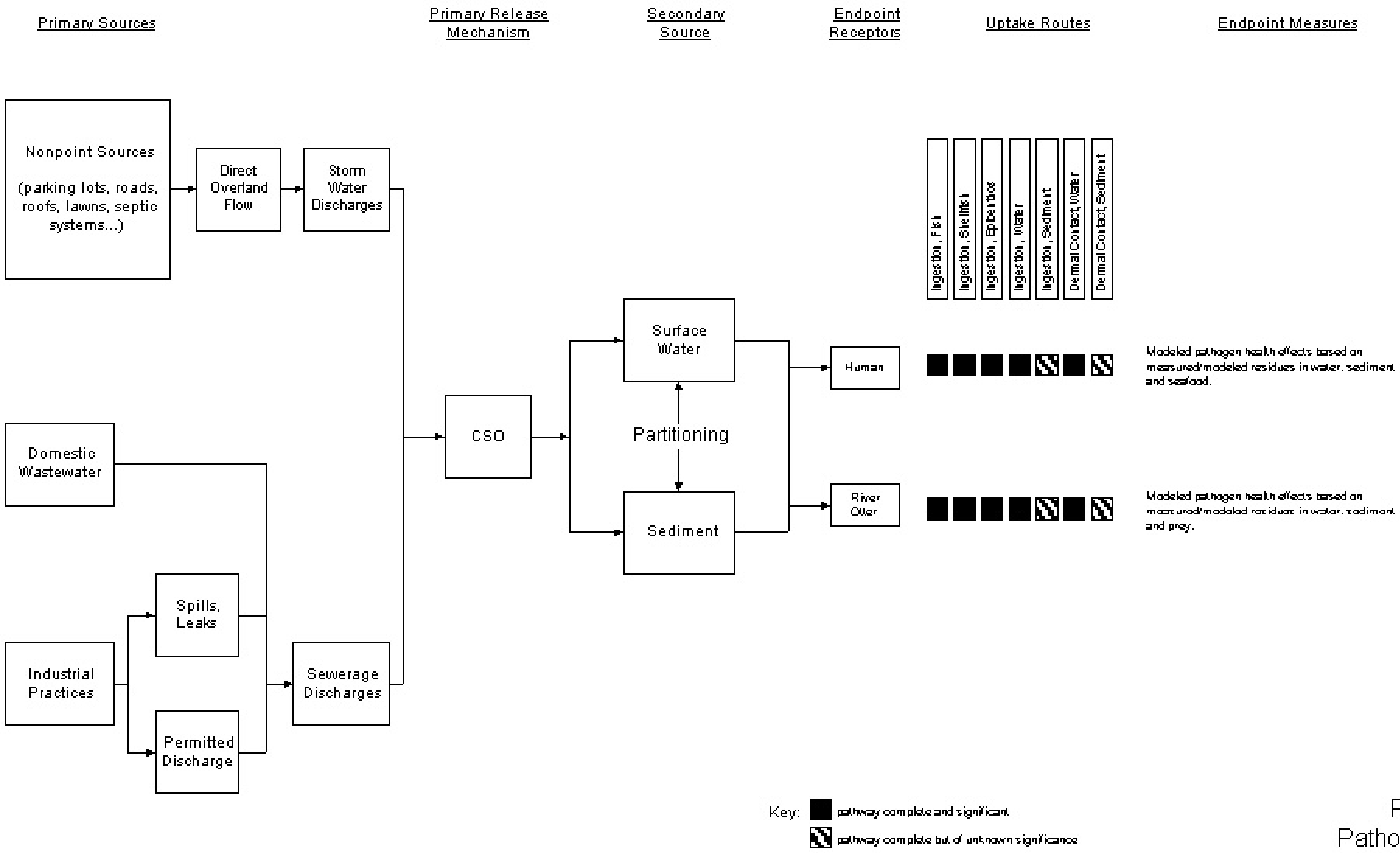



Figure 3-10
Pathogens Pathway - CSO Risk

flow, the bathymetry of the channel into which the runoff or discharge occurs, and the particle size of sediments present in the channel bed or added to the flow by resuspension or the discharge. Scouring affects benthic infaunal communities by displacement, while sedimentation affects benthic infaunal communities by smothering. Resuspension of sediments during erosion can also result in the re-release of chemicals and toxicity for exposed aquatic organisms, wildlife, and people.

***Changes in Water Quality Parameters.*** Runoff and CSO discharges can change conventional water quality parameters such as lowering the salinity of receiving waters. If either source contains organic materials or nutrients, they also have the potential to affect DO concentration and pH. Additionally, CSOs discharges may be warmer than the receiving waterbody. Lowered salinity, DO, pH, and temperature changes can affect most aquatic life.

***Microbial Contaminants.*** Microbial COPCs include bacterial, parasitic, and viral pathogens that enter the Duwamish Estuary in untreated domestic wastewaters. Failing septic systems and CSOs are primary sources of poorly treated or untreated domestic wastewaters. Pathogens of human origin persist for varying durations in water, in sediments, and in shellfish. They mainly affect people but also can possibly affect other mammals such as the river otter.

### 3.10.2 Risk Hypotheses: Effects of Stressors on Ecological Receptors

Based on the conceptual models shown in Figure 3-5 through Figure 3-10, a wide range of hypotheses concerning the effects of CSO and other discharges on the aquatic ecosystem and human health can be developed. Hypotheses are presented that address the potential risks associated with toxic chemicals, physical disturbance, other physical changes, and microbial contaminants. Distinction is made between risks from all sources including CSOs (baseline risk) and the risks associated with just CSOs (CSO risk). Risk hypotheses are first expressed as narratives then summarized in the following sections.

***Toxic Chemicals.*** Toxic chemicals may affect survival, growth, and reproduction of a wide range of species including migrant and resident fish, epibenthos and benthic infauna, spotted sandpiper, great blue heron, bald eagle, and river otter. Potential toxic effects are the result of intermittent or continuous discharges of chemicals from both point and non-point sources. Toxic chemicals also may affect community structure, particularly of benthic infaunal organisms, and may reduce the ability of a community to sustain (provide food for) populations of other organisms. Changes in benthic community structure may be reflected in the numbers of each species present (abundance) as well as the numbers of species present (diversity).

Potential toxic effects to the same organisms can result from intermittent CSO discharges associated with wet weather events that vary in frequency, magnitude, and duration. While CSO inputs are intermittent, they have the potential to impact both the water column and sediments. Their impact on sediment-dwelling organisms may be acute (short-term lethal) or chronic (longer-term and sublethal).

Baseline risk for the biological resources of the Duwamish River and Elliott Bay will be assessed using modeled or measured concentrations of chemicals found in water, sediments, and organisms that come from all sources. CSO-related risk for the biological resources will be assessed using modeled or measured concentrations of toxic chemicals found in water, sediments, and biota that come only from CSOs.

<u>Summary Hypothesis:</u> Elevated chemical baseline concentrations result in reduced survivorship and reproduction of aquatic life and wildlife resources present in the Duwamish River and Elliott Bay. Chemicals present in intermittent CSO discharges result in reduced survivorship and reproduction of aquatic life and wildlife resources present in the Duwamish River and Elliott Bay.

***Physical Disturbance.*** Seasonal runoff may physically affect intertidal and shallow subtidal habitats through erosion and sedimentation, reducing the abilities of these habitats to sustain (provide food for) populations of other organisms. In winter and early spring, runoff can erode intertidal and shallow subtidal habitats displacing benthic communities though destruction of habitat. In late spring and summer with the build-up of sediments, intertidal and shallow subtidal sediments recolonize with a wide variety of organisms. These changes in the benthic community are reflected in the numbers of each species present (abundance) as well as the number of species present (diversity).

CSO discharges also may physically affect intertidal and shallow subtidal habitats reducing their abilities to sustain populations of other organisms. Most CSOs have considerable head and discharge at high velocities. In winter, CSOs overflow and erode the substrate displacing benthic communities. If the CSO discharges to the intertidal or shallow subtidal zones, erosion can be significant. Over the spring and summer when CSO discharges are infrequent, the sediments below a CSO buildup and are colonized by a wide variety of invertebrates. Physical disturbance to benthic habitats caused by CSO discharge is thought to be limited to a relatively small area below each CSO.

Baseline risks for the biological resources of the Duwamish River and Elliott Bay will be assessed from impacts to benthic communities associated with seasonal runoff while CSO risks will be assessed on impacts to benthic communities that occur below CSO discharges.

<u>Summary Hypothesis:</u> Changes in the physical structure of receiving waters resulting from seasonal runoff result in reduced survivorship and reproduction of aquatic life and wildlife resources present in the Duwamish River and Elliott Bay. Changes in the physical structure of receiving waters resulting from intermittent CSO discharges result in reduced survivorship and reproduction of aquatic life and wildlife resources present in the Duwamish River and Elliott Bay.

***Changes in Water Quality Parameters.*** Both runoff and CSO discharges may lower salinity, DO, and pH, which can affect survival, growth, and reproduction of a wide variety of aquatic animals. Potential temperature increases associated with CSO discharges can similarly affect these same endpoints.

Baseline risks for the biological resources of the Duwamish River and Elliott Bay will be assessed using modeled or measured salinity, DO, pH, and temperature regimes in the Duwamish Estuary occurring during the wet or runoff season. CSO risks will be assessed using modeled or measured salinity, DO, pH, and temperature regimes occurring in the plumes of CSOs.

Summary Hypothesis: Changes in water quality parameters in ambient waters resulting from seasonal runoff results in reduced survivorship and reproduction of aquatic life and wildlife resources present in the Duwamish River and Elliott Bay. Changes in water quality parameters resulting from intermittent CSO discharges result in reduced survivorship and reproduction of aquatic life and wildlife resources present in the Duwamish River and Elliott Bay.

### 3.10.3 Risk Hypothesis: Effects of Stressors on Human Health

***Toxic Chemicals.*** People are most at risk from toxic chemicals through either direct contact with contaminated water and sediments or through ingestion of contaminated fish and shellfish. Exposure can result in cancer and non-cancer health effects. Concentration and persistence in the environment varies with the type of chemical. Ingestion of chemicals in water or sediments is possible but is thought to be insignificant. Some people may be at greater risk than the general population because they eat more seafood from the Duwamish River and Elliott Bay.

Baseline risk for people using the Duwamish River and Elliott Bay will be assessed using modeled or measured concentrations of chemicals found in water, sediments, and subsistence food coming from all sources. CSO-related risks will be assessed using modeled or measured concentrations of chemicals discharged by CSOs.

Summary Hypothesis: People using the Duwamish River/Elliott Bay system for recreation (e.g., swimming, fishing, and boating) and subsistence food gathering are at increased risk of non-carcinogenic and carcinogenic health effects from elevated chemical baseline concentrations in surface waters, sediment, fish, and shellfish. People using the Duwamish River/Elliott Bay system for recreation (e.g., swimming and fishing) and subsistence food gathering are at increased risk of non-cancer and cancer health effects from elevated chemical concentrations in intermittent CSO discharges to surface waters and sediments.

***Microbial Contaminants.*** Microbial contaminants, including bacteria, viruses, and parasites, enter the Duwamish River and Elliott Bay through discharge of poorly treated or untreated wastewaters. Failing septic systems, CSO discharges, and treatment plant discharges are potential sources of contaminants. Bacteria and viruses vary in persistence in water, sediments and in shellfish, particularly mussels, clams, and oysters.

People are most at risk from either direct contact with contaminated water and sediments or from ingestion of contaminated fish and shellfish. Exposure can result in infection leading to acute or chronic illness. Some subpopulations may be at greater risk than the general population due to increased frequency and duration of exposure. Others are at increased risk because of compromised immune systems.

Baseline risk for people using the Duwamish River and Elliott Bay will be assessed using modeled or measured concentrations of microbial contaminants in water, sediments, and biota arising from all sources. CSO risks will be assessed using modeled or measured concentrations of microbial contaminants in water, sediments, and biota resulting from CSO discharges.

<u>Summary Hypothesis:</u> People using the Duwamish River/Elliott Bay system for recreation (e.g., swimming, fishing, and boating) and subsistence food gathering are at increased risk of infection and symptomatic illness from elevated concentrations of microbial contaminants present at baseline conditions in surface waters, sediment, fish, and shellfish. People using the Duwamish River/Elliott Bay system for recreation and subsistence food gathering are at increased risk of infection and symptomatic illness from elevated concentrations of microbial contaminants present in intermittent CSO discharges to surface waters and sediments.

# 4. References

Adam, R.D. 1991. The biology of *Giardia* sp. Microbiol. Rev. 55(4)706-732.

Ahmed, F.E. 1992. Review: assessing and managing risk due to consumption of seafood contaminated with micro-organisms, parasites, and natural toxins in the U.S. International Journal of Food Science and Technology. 27:243-260.

Alexander, L.M., A. Heaven, A. Tennant, and R. Morris. 1992. Symptomatology of Children in contact with sea water contaminated with sewage. Journ. of Epidem. and Comm. Hlth. 46:340-344.

Anderson, D.L., A.L. Lewis, and K.M. Sherman. 1991. Human enterovireus monitoring at onsite sewage disposal systems in Florida. pg 94-104. *In:* Proceedings of the sixth national symposium on individual and small community sewage systems: On-Site Wastewater Treatment. Volume 6. Published by Amer Society of Agri Engineers, Michigan.

Arkoosh, M.R., E. Casillas, E. Clemons, B.B. McCain, and U. Varanasi. 1991. Suppression of immunological memory in juvenile Chinook salmon (*Oncorhynchus tshawytcha*) from an urban estuary. Fish and Shellfish Immunol. 4:261-278.

Armstrong, J.W., R.M. Thom, and K.K. Chew. 1980-1981. Impact of a combined sewer overflow on the abundance, distribution and community structure of subtidal benthos. Marine Environmental Research 4:3-23.

Ballarajan, R., V. Soni Raleigh, P. Yuen, D. Wheeler, D. Machin, and R. Cartwright. 1991. Health risks associated with bathing in sea water. Brit. Med. J. 303::1444-1445.

Barnthouse, L.W. and G.W. Sutter II (editors). 1986. User's manuals for ecological risk assessment. Oak Ridge National Laboratory. Report No. ORNL-6251. Oak Ridge, Tennessee

Benenson A.S. 1995. Control of communicable disease in man. Sixteenth Edition, American Public Health Association. Washington, DC .

Bennett, J.V., S.D. Homberg, M.F. Rogers, and S.L. Solomon. 1987. Infectious and Parasitic Diseases. Am. J. Preventive Med. 55:102-114.

Blomberg, G., C. Simenstad, and P. Hickey. 1988. Changes in habitat composition of the Duwamish River estuary over the past century. *In*: Proceedings of the First Annual Meeting on Puget Sound Research. Volume 2. Puget Sound Water Quality Authority, Seattle, Washington.

Buhler, D.R. and D.E. Williams. 1989. Enzymes involved in metabolism of PAH by fishes and other aquatic animals: oxidative enzymes (or phase 1 enzymes). *In*: U. Varnasi, Ed., Metabolism of polycyclic aromatic hydrocarbons in the aquatic environment. CRC Press, Inc., Boca Raton, FL, pp. 151-184.

Cabelli, V.J., A.P. Dufour, M.A. Levin, L.J. McCabe, and P.W. Haberman, 1979. Relationship of microbial indicators to health effects at marine bathing beaches. American Journal of Public Health. 69(7):690-696.

Cabelli, V.J., A.P. Dufour, L.J. McCabe, and M.A. Levine. 1982. Swimming-associated gastroenteritis and water quality. American Journal of Epidemiology. 115(4):606-616.

Calambokidis, J., S.M. Speich, J. Peard, G.H. Steiger, J.C. Cubbage, D.M. Fry, and L.J. Lowenstine. 1985. Biology of Puget Sound marine mammals and marine birds: Population health and evidence of pollution effects. NOAA Tech. Mem. NOS OMA 18, Nat. Tech. Info. Serv., Springfield, VA 167 pp.

Calambokidis, J., J.B. Buchanan, G.H. Steiger, and J.R. Evenson. 1991. Toxic contaminants in Puget Sound wildlife. U.S. Environmental Protection Agency, Seattle, Washington. 96 pp.

Canning, D.J., S.G. Herman, and G.B. Shea. 1979. Terminal 107 environmental studies, wildlife study. Prepared for the Port of Seattle. Oceanographic Institute of Washington and Northwest Environmental Consultants. Seattle, Washington.

Casillas, E., D.A. Misitano, L.L. Johnson, L.D. Rhodes, T.K. Collier, J.E. Stein, B.B. McCain, and U. Varanasi. 1991. Inducibility of spawning and reproductive success of female English sole, (*Parophyrys vetulus*) from urban and nonurban areas of Puget Sound, Washington. Mar. Environ. Res. 31:99-122.

Casillas, E., J.E. Stein, M.R. Arkoosh, D.W. Brown, D.A. Misitano, S-L. Chan, and U. Varanasi. 1993. Effects of estaurine habitat quality on juvenile salmon: I. Chemical contaminant exposure and II, Altered growth and immune function. *In*: Coastal Zone-93 Proceedings, The Eight Symposium on Coastal and Ocean management, New Orleans, Louisiana. pp. 548-562.

Centers for Disease Control (CDC). 1996. Surveillance for foodborne-disease outbreaks-United States, 1988-1992. Morbidity Mortality Weekly Report 45: No.SS-5, 1-65.

Centers for Disease Control (CDC). 1997. Viral gastroenteritis associated with eating oysters – Louisiana, December 1996-January 1997. Morbidity and Mortality Weekly Report, November 28. 46(47):1109-1112.

City of Tampa. 1993. City of Tampa Water Resources Recovery Project, pilot studies. Final Report. $CH_2M$ Hill, City of Tampa, Florida Department of Environmental Regulation. West Coast Regional Water Supply Authority.

Collier, T.K. and U. Varanasi. 1991. Hepatic activities of xenophobic metabolizing enzymes and biliary levels of xenobiotics in English sole (*Parophyrys vetulus*) exposed to environmental contaminants. Arch. Environ. Contam. Toxicol. 20: 462-473.

Corbett, S.J., G.L. Rubin, G.K. Curry, D.G. Kleinbaum, and the Sydney Beach Users Study Advisor Group. 1993. The health effects of swimming at Sydney beaches. American Journal of Public Health. 83(12):1701-1706.

Craun, G.F.M (ed.) 1986. Waterborne Disease in the United States. CRC Press. Boca Raton, Florida.

Dadswell, J.V. 1993. Microbiological quality of coastal waters and its health effects. International Journal of Environmental Health Research. 3(1):32-46.

Danielson, R.E., L.A. Pettegrew, J.A. Soller, A.W. Olivieri, D.M. Eisenberg, and R.C. Cooper. 1996. A microbiological comparison of a drinking water supply and reclaimed wastewater for direct potable reuse. Paper presented at joint AWWA and WEF Water Reuse 96 Conference held in San Diego, California.

Dubey, J.P., C.A. Speer, and R. Fayer. 1990. Cryptosporidiosis of man and animals. CRC Press, Boca Raton, Florida.

Ewell, W.S, J.W. Gorsuch, R.O. Kringle, K.A. Robillard, and R.C. Spiegel. 1986. Simultaneous evaluation of the acute effects of chemicals on seven aquatic species. Environmental Toxicology and Chemistry 5: 831-840.

Fewtrell, L., A.F. Godfree, F. Jones, D. Kay, R.L. Salmon, and M.D. Wyer. 1992. Health effects of white-water canoeing. Lancet. 339:1587-1589.

Fleisher, J.M., D. Kay, R.L. Salmon, F. Jones, M.D. Wyer, and A.F. Godfree. 1996. Marine waters contaminated with domestic sewage: nonenteric illnesses associated with bather exposure in the United Kingdom. Amer. J. Pub. Hlth. 86:1228-1234.

Gerba, C.P., S.N. Singh, and J.B. Rose. 1985. Waterborne viral hepatitis and gastroenteritis. CRC Crit. Rev. Environ. Control. 15:213-236.

Gibson, C.J. , Stadterman, K.L., States, and S., Sykora, J. 1998. Combined sewer overflows: a source of *Cryptosporidium* and *Giardia*. Wat. Sci. Tech. Submitted.

Grabow, W.O.K., B.W. Bateman, and J.S. Burger. 1978. Micrbiological quality indicators for routine monitoring of wastewater reclamation systems. Prog. Wat. Tech. 10:317-327

Haile, R.W., J. Alamillo, K. Barrett, R. Cressey, J. Dermond, C. Ervin, A. Glasser, N. Harawa, P. Harmon, J. Harper, C. McGee, R.C. Millikan, M. Nides, and J.S. White. 1996. An epidemiological study of possible adverse health effects of swimming in Santa Monica Bay. Final Report. Santa Monica Bay Restoration Project, Santa Monica, California.

Hancock, C.M., J.B. Rose, and M.Callahan. 1998. Crypto and *Giardia* in U.S. groundwater. J. AWWA, 90, (3) 58-61.

Herricks, E.E., I. Milne, and I. Johnston. 1995. Region specific timescale toxicity in aquatic ecosystems. Project 92-BAR-1. Annual Report 1995. Water Environment Research Foundation. Alexandria, Virginia.

Herwaldt, B.L., C.F. Craun, S.L. Stokes, and D.D. Juranek. 1991. Waterborne disease outbreaks--United States, 1989-1990. Morbidity and Mortality Weekly Report, Centers for Disease Control Surveillance Summaries. 40(SS-3):1-21.

Heyward, A.A., S.F. Munger, and R.G. Swartz. 1977. A survey of the microbiological quality of shellfish on King County beaches. Municipality of Metropolitan Seattle. Seattle, Washington.

Irving, L.G. 1982. Viruses in wastewater effluents. P.7. *In:* Viruses and Disinfection of Water and Wastewater. Butler, M., R. Medlen, and R. Morris, eds. United Kingdom: University of Surry.

Johnson, L.L., E. Casillas, T.K. Collier, B.B. McCain, and U. Varanasi. 1988. Contaminant effects on ovarian development in English sole (*Parophrys vetulus*) from Puget Sound, Washington. Can. J. Fish. Aquat. Sci. 45: 2133-2146.

Johnson, L.L., E. Casillas, T.K. Collier, B.B. McCain, and U. Varanasi. 1993. Contaminant effects on reproductive success in selected benthic fish species. Mar. Env. Res. 35:165-170

Johnson, L.L., M.S. Meyers, D. Goyette, and R.F. Addison. 1994. Toxic chemicals and fish health in Puget Sound and the Georgia Strait. Canadian Technical Report of Fisheries and Aquatic Sciences. 1948:304-329.

Klingel, K., C. Hohenadl, A. Canu, M. Albrecht, M. Seemann, G. Mall, and R. Kandolf. 1992. Ongoing enterovirus-induced myocarditis is associated with persistent heart muscle infection: quantitative analysis of virus replication, tissue damage and inflammation. Proceeding of the National Academy of Science. 89:314-318.

King County Department of Metropolitan Services (King County). 1995a. The Denny Way sediment cap 1990 - 1992 Data. King County. Seattle, Washington.

King County Department of Metropolitan Services (King County). 1995b. Combined sewer overflow control plan 1995 update, an amendment to Metro's comprehensive water pollution control abatement plan. Prepared for King County Department of Metropolitan Services by Brown and Caldwell, KCM, and Associated Firms. Seattle, Washington.

King County Department of Natural Resources (King County). 1995c. Water quality assessment. King County. Seattle, Washington.

King County Water Pollution Control Division. 1996. Norfolk CSO sediment cleanup study: Elliott Bay/Duwamish restoration program. Prepared for the Elliott Bay/Duwamish Restoration Program Panel by the King County Water Pollution Control Division. Panel Publication 13.

Kiode, H., Y. Kitaura, H. Deguchi, A. Ukimura, K. Kawamura, and K.Hirai. 1992. Genomic detection of enteroviruses in the myocardium studies on animal hearts with Coxsackievirus B3 Myocarditis and endomyocardial biopsies from patients with Myocarditis and dilated cardiomyopathy. Japanese Circulation Journal 56:1081-1093.

Krahn, M.M., D.G. Burrows, W.D. McLeod, Jr., and D.C. Malins. 1987. Determination of individual metabolites of aromatic hydrocarbons in hydrolysed bile of English sole, (*Parophrys vetulus*) from polluted sites in Puget Sound, Washington. Arch. Environ. Contam. 16:511-522.

Landolt, M., D. Kalman, A. Nevissi, G. van Belle, K. Van Ness, and F. Hafer. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound: Final report. NOAA Technical Memorandum. NOS OMA 33. National Oceanic and Atmospheric Administration, Rockville, MD.

Lauer, W.C. 1991. Water quality for potable reuse. Wat. Sci. and Tech. 23:2171-2180.

Le Guyader, F., F.H. Neill, M.K. Estes, S.S. Monroe, T. Ando, and R.L. Atmar. 1996. Detection and analysis of small round-structured virus strain in oysters implicated in an outbreak of acute gastroenteritis Appl. Env. Microbiol. 62, 4268-4272.

Levine, W.C. and C.F. Craun. 1990. Waterborne disease outbreaks--United States, 1986-1988. Morbidity and Mortality Weekly Report, Centers for Disease Control Surveillance Summaries. 39(SS-1):1-13.

Lipp E.K. and J.B. Rose. 1997. The role of seafood in foodborne diseases in the United States of America. *In:* Rev. Sci Tech. Off Int. Epiz. 16 (2):620-640.

Lisle, J.T. and J.B. Rose. 1995. Cryptosporidium contamination of water in the USA and UK: a mini review. J Water SRT-Aqua. 44(3):103-117.

Luthi, T.M., P.G. Wall, H.S. Evans, G.K. Adek, and E.O. Caul. 1996. Outbreaks of foodborne viral gastroenteritis in England and Wales: 1992 to 1994. Communicable Disease Report. 13 September. 6(10):R131-R136.

Malins, D.C., B.B. McCain, D.W. Brown, S-L, Chan, M.S. Meyers, J.T. Landahl, P.G. Prohaska, A.J. Friedman, L.D. Rhodes, D.G. Burrows, W.D. Gronlund, and H.O. Hodgins. 1984. Chemical pollutants in sediments and disease in bottom-dwelling fish in Puget Sound, Washington. Environ. Sci. Technol. 18: 705-713.

Malins, D.C., M.M. Krahn, M.S. Meyers, L.D. Rhodes, C.A. Wigren, D.W. Brown, C. Crone, B.B. McCain, and S-L. Chan. 1985. Toxic chemicals in sediments and biota from a creosote-polluted harbor: Relationships with hepatic neoplasms and other hepatic lesions in English sole (*Parophrys vetulus*). Carcinogenesis 6: 1463-1469.

McCallum, M. 1985. Recreational and substistence catch and consumption of seafood from three urban bays of Puget Sound: Port Gardner, Elliott Bay and Sinclair Inlet. Washington State Division of Health, Epidemiology Section. Olympia, Washington.

McDonnel, S., K.B. Kirkland, W.G. Hlady, C. Aristeguieta, R.S. Hopkins, S.S. Monroe, and R.I. Glass. 1997. Failure of cooking to prevent shellfish-associated viral gastroenteritis. Ach. Intern. Med. January 13. 157:111-116.

Melnick, J.L. 1995. History and epidemiology of hepatitis A virus. J. Infect. Dis. 171:2-8.

Meyers, M.S., J.T. Landahl, and B.B. McCain. 1987. Pathologic anatomy and patterns of occurrence in hepatic neoplasm, putative preneoplastic lesions and other idiopathic conditions in English sole, (*Parophrys vetulus*) from Puget Sound, Washington. J. Nat. Can. Inst. 78: 333-363.

Meyers, M.S., J.T. Landahl, M.M. Drahn, L.L. Johnson, and B.B. McCain. 1990. Overview of studies on liver carcinogenisis in English sole from Puget Sound; evidence for a xenobiotic chemical etiology. I: Pathology and epizootiology. Sci. Total Environ. 94: 33-50.

Meyers, M.S., O.P. Olson, L.L. Johnson, C.M. Stehr, T. Hom, and U. Varanasi. 1992. Hepatic lesions other than neoplasms in subadult flatfish from Puget Sound, Washington: relationships with indices of contaminant exposure. Mar. Env. Res. 34: 45-51.

Meyers, M.S., C.M. Stehr, O.P. Olson, L.L. Landahl, B.B. McCain, S-L Chan, and U. Varanasi. 1994. Relationships between toxicopathic hepatic lesions and exposure to chemical contaminants in English sole (*Pleuronectes vetulus*), starry flounder, (*Platichthys stellatus*), and white croaker (*Genyonemus lineatus*) from selected marine sites on the Pacific Coast, USA. U.S. Environ. Health Prespect. 102(2):2-17.

Meyers, M.S., L.L. Johnson, D.P. Lomax, B.H. Horness, M.L. Landolt, and S. O'Neill. 1995. Relationships between hepatic lesion prevalence in English sole (*Pleuronectes vetulus*) and sediment levels of chemical contaminates in Puget Sound: establishing threshold levels of sublethal effects. *In*: Puget Sound Research '95 Proceedings. January 12-14, 1995. Puget Sound Water Quality Authority, Olympia, Washington.

Moore, A.C., B.L. Herwaldt, C.F. Craun, R.L. Calderon, and A.K. Highsmith. 1993. Surveillance for waterborne disease outbreaks--United States, 1991-1992. Morbidity and Mortality Weekly Report, Centers for Disease Control Surveillance Summaries. 42(SS-5):1-22.

Munger, S.F. 1983. Bacterial characterization of wastewater sludge. Masters Thesis, School of Public Health and Community Medicine, University of Washington. Seattle, Washington.

National Resource Defense Council (NRDC). 1998. Testing the waters: closings, costs and cleanup at U.S. beaches.

Norman, D. 1995. The status of great blue herons in Puget Sound: population dynamics and recruitment hypotheses. *In*: Proc. Puget Sound Research '95, January 12-14, 1995. Puget Sound Water Quality Authority, Olympia, Washington.

Oakley, K. 1976. Eggshell thickness and chlorinated hydrocarbon residues in the eggs of Pigeon Guillemot (*Crepphus columbia*) in Puget Sound. Unpub. report. The Evergreen State College. Olympia Washington.

O'Niell, S.M., J.E. West, and S. Quinell. 1995. Contaminant monitoring in fish: overview of the Puget Sound Ambient Monitoring Program fish task. *In*: Proc. Puget Sound Research 95, January 12-14, 1995. Puget Sound Water Quality Authority. Olympia, Washington.

O'Shea, M.L., and R. Field. 1992 Detection and disinfection of pathogens in storm-generated flows. Can. J. Micriobiol. 38:267-276.

Parametrix, Inc. 1991. Risk assessment for Wollongong, NSW: reuse of secondary-treated sewage effluent Wollongong, Illawarra, NSW. Prepared for Sydney Waterboard, Sydney, Australia by Parametrix, Inc. Bellevue, Washington.

Parkhurst, B.R., W. Warren-Hicks, R.D. Cardwell, J. Volison, T. Etchison, J.B. Butcher, and S. M. Covington. 1996. Aquatic ecological risk assessment: a multi-tiered approach. Project 91-AER-1. Water Environment Research Foundation. Alexandria, Virginia.

Pastorok, R.A., P.N. Booth, and L.G. Williams. 1986. Estimating potential health risks of chemically contaminated seafood. Puget Sound Notes: May Issue, pages 3-6. State of Washington, Department of Ecology. Olympia, Washington.

Paulson, D. 1993. Shorebirds of the Pacific Northwest. University of Washington Press. Seattle, Washington.

Popovich, G.G. and V.I. Bondarenko. 1989. Infection of humans with enterobacteria and enteroviruses during swimming, depending on the level of microbial contamination of water. Trans. by SCITRAN Company. Zhurnal Microbiologii, Epidemiologii i Immunologii. 3:45-47.

Pruss, A. 1998. Review of epidemiological studies on health effects from exposure to recreational water. International Journal of Epidemiology. 27:1-9.

PTI Environmental Services and Tetra Tech, Inc. (PTI and Tetra Tech). 1988. Elliott Bay Action Program: analysis of toxic problem areas. Final Report TC 3338-23. Prepared for U.S. Environmental Protection Agency, Region X, Office of Puget Sound by PTI Environmental Services and Tetra Tech, Inc. Bellevue, Washington.

Rao, V.C., K.M. Seidel, S.M. Goyal, T.G. Metcalf, and J.L. Melnick. 1984. Isolation of enteroviruses from water, suspended solids, and sediments from Galveston Bay: Survival of Poliovirus and Rotavirus Adsorbed to Sediments. Appl. Env. Microbio. 48:404-409.

Riley, R.G., E.A. Crecelius, R.E. Fitzner, B.L. Thomas, J.M. Gutisen, and N.S. Bloom. 1983. Organic and inorganic toxicants in sediments and marine birds from Puget Sound. NOAA Technical Memorandum NOS OMS 1. 125pp.

Romberg, G.P., S.P. Pavlou, R.F. Shokes, W. Hom, E.A. Crecelius, P. Hamilton, J.T. Gunn, R.D. Muench, and J. Vinelli. 1984. Toxicant pretreatment planning study technical report C1: presence, distribution and fate of toxicants in Puget Sound and Lake Washington. Municipality of Metropolitan Seattle (Metro). Seattle, Washington.

Romberg, P., D. Healy, and K. Lund. 1987. Toxicant reduction in the Denny Way combined sewer system. The Municipality of Metropolitan Seattle. Seattle, Washington.

Rose, J.B., C.N. Haas, and S. Regli. 1991. Risk assessment and control of waterborne Giardiasis. Am. J. Pub. Hlth. 81:709-713.

Rose, J.B., L.J. Dickson, S.R. Farrah, and R.P. Carnahan. 1996. Removal of pathogenic and indicator microorganisms by a full-scale water reclamation facility. Wat. Res. 30(11): 2785-2797.

Rose, J.B., M. Robbins, D.E. Friedman, C.L. Hamann, K. Riley, and S.R. Farrah. 1996. Evaluation of upper occoquan sewage authority water reclamation plant processes for the removal of microorganisms. Water Reuse 96. February 25-28. San Diego, California.

Rose, J.B. 1997. Environmental ecology of *Cryptosporidium* and public health implications. Annual Reviews of Public Health. 18:135-161.

Schaiberger, G.E., T.D. Edmond, and C.P. Gerba. 1982. Distribution of enteroviruses in sediments contiguous with a deep marine sewage outfall. Wat. Res. 16:1425-1428.

Speich, S.M., J. Calambokidis, S.W. Shea, J. Peard, M. Witter, and D.M. Fry. 1992. Eggshell thinning and organochlorine contaminants in western Washington water birds. Colonial Waterbirds 15(1):103-112.

Stein, J.E., T.K. Collier, W.L. Reichert, E. Casillas, T. Hom, and U. Varanasi. 1992. Bioindicators of contaminant exposure and sublethal effects: studies with benthic fish in Puget Sound, Washington. Environ. Toxicol. Chem. 11:701-714.

Stober, Q.J. and K.B. Pierson. 1984. A review of the water quality and marine resources of Elliott Bay, Seattle, Washington. Prepared for URS Engineers and the Municipality of Metropolitan Seattle, Seattle, Washington. Fisheries Research Institute, University of Washington. Seattle, Washington.

Stuart, R.E. and R.D. Cardwell. 1987. Aquatic ecological risk assessment of lead, copper, phthalates and polynuclear aromatic hydrocarbons dishcharge via stormwaters and combined sewer overflows into an urban lake. Prepared for Municipality of Metropolitan Seattle by Envirosphere Company. Bellevue, Washington.

Sullivan, C.S.B. and M.E. Barron. 1989. Acute illness among Los Angeles County lifeguards according to worksite exposures. American Journal of Public Health. 79(11)1561-1563.

Suter, G.W. and A.E. Rosen. 1986. Comparative toxicology of marine fishes and crustaceans. NOAA, National Ocean Service. Rockville, Maryland. NTIS No. PB87-1151916.

Tanner, C.D. 1991. Potential intertidal habitat restoration sites in the Duwamish Estuary. Prepared for the Port of Seattle Engineering Department and the U.S. Environmental Protection Agency, Environmental Evaluations Branch. Seattle, Washington.

Tetra Tech, Inc. (Tetra Tech). 1988. Health risk assessment of chemical contamination in Puget Sound seafood. Final Report TC-3338-28 prepared for U.S. Environmental Protection Agency. Tetra Tech, Inc. Bellevue, Washington.

Toy, K.A., N.L. Polisaar, S. Liao, and G.D. Mittelstaedt. 1996. A fish consumption survey of the Tulalip and Squaxin Island Tribes of the Puget Sound region. Tulalip Tribes, Department of Environment. Marysville, Washington.

U.S. Environmental Protection Agency (U.S. EPA). 1988. Evaluation of potentail contaminant sources. Prepard for the Elliott Bay Action Program by Tetra Tech. Seattle, Washington.

U.S. Environmental Protection Agency (U.S. EPA). 1989. Risk assessment guidance for superfund. Volume 1. Human health evaluation manual (Part A). EPA/540/1-89/002. Office of Emergency and Remedial Response, U.S. EPA. Washington, D.C.

U.S. Environmental Protection Agency (U.S. EPA). 1992. Guidance for data usability in risk assessment (Part A). PB92-963356. Office of Emergency and Remedial Response, U.S. EPA. Washington, D.C.

U.S. Environmental Protection Agency (U.S. EPA). 1994. Guidance for assessing chemical contaminant data for use in fish advisories. Volume 11. Risk Assessment and Fish Consumption Limits. EPA 823-B-94-004.

U.S. Environmental Protection Agency (U.S. EPA). 1996. Proposed guidelines for ecological risk assessment. EPA/630/R-95/002B. Risk Assessment Forum, U.S. Environmental Protection Agency. Washington, D.C.

Varanasi, U., J.E. Stein, and M. Nishimoto. 1989. Formation and persistence of benzo(a)pyrenediolepoxide-DNA adducts in liver of English sole (*Parophrys vetulus*). Chem.-Biol. Interactions 69: 203-216.

Varanasi, U., E. Casillas, M.R. Arkoosh, T. Hom, D.A. Misitano, D.W. Brown, S-L. Chan, T.K. Collier, B.B. McCain, and J.E. Stein. 1993. Contaminant exposure and associated biological effects in juvenile Chinook salmon (*Oncorhynchus tshawytshca*) from urban and nonurban estuaries of Puget Sound. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-FWFSC-8, 112 p.

Volmer, J., W. Kordel, and W. Klein. 1983. A proposed method for calculating taxonomic-group-specific variances for use in ecological risk assessment. *Chemosphere* 17(8).

Wagenknecht, LE, J.M. Roseman, and W.H. Herman. 1991. Increased incidence of insulin-dependent diabetes mellitus following an epidemic of coxsackievirus B5. American Journal of Epidemiology 133:1024-1031.

Warner, E.J., and R.L. Fritz. 1995. The distribution and growth of Green River chinook salmon, (*Oncorhynchus tshawytshca*), and chum salmon (*Oncorhynchus keta*) Outmigrants in the Duwamish Estuary as a Function of Water Quality and Substrate. Muckleshoot Indian Tribe. Auburn, Washington.

Washington State Department of Health (WSDOH). 1993. Annual inventory of commercial and recreational areas in Puget Sound. Washington State Department of Health, Shellfish Programs. Olympia Washington.

Washington State Department of Ecology (WSDOE). 1994. West coast marine species chronic protocol variability study. Prepared by PTI Environmental Services, Bellevue, Washington.

Washington State Department of Ecology (WSDOE). 1996. Sediment management standards contaminated sediment site list. Ecology. Olympia, Washington.

Washington State Department of Wildlife (WSDOW). 1991. Management recommendations for Washington priority habitats and species. Washington Department of Wildlife. Olympia, Washington.

Weingold, S.E., J.J. Guzewich, and J.K. Fudala. 1994. Use of foodborne disease data for HAACP risk assessment. J. Food Protection 57:820-830.

Yanko, W.A. 1993. Analysis of 10 years of virus monitoring data from Los Angeles Country treatment plants meeting California wastewater reclamation criteria. Wat. Environ. Res. 65(3):221-226

Yates, M.V. and S.R. Yates. 1988. Modeling microbial fate in the subsurface environment. Critical Reviews in Environmental Control 17:307-343.

# 5. GLOSSARY

**Assessment endpoint** - An explicit expression of the environmental value that is to be protected.

**Bioaccumulation** - The uptake of chemicals by aquatic organisms from water and/or through consumption of food.

**Bioconcentration** - The uptake of chemicals by aquatic organisms from water.

**Biomagnification** - The increase in chemicals in organisms at successively higher trophic levels as a consequence of ingesting contaminated organisms from lower trophic levels.

**Benthos** - The community of aquatic organisms living in or on the bottom sediments.

**Carcinogenic** - Capable of causing cancer.

**Constituent of Potential Concern (COPC) –** Chemical, physical or biological constituents in the environment that potentially pose risk.

**Combined Sewer Overflow (CSO)** - Discharges of combined sewage and storm water during wet weather. It occurs to relieve the sewer system as it becomes overloaded with normal sewer flow and increased storm runoff. The term is also used to denote a pipe that discharges these flows.

**Conceptual model -** A conceptual model describes a series of working hypotheses of how a stressor might affect ecological components. The conceptual model also describes the ecosystem potentially at risk, the relationships between measures of effect and assessment endpoints, and exposure scenarios.

**Community** - An assemblage of populations of different species within a specified location in space and time.

**Disturbance -** Any event or series of events that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.

**Diversity** - A measure (index) to characterize the numbers of different aquatic organisms (different taxa) that inhabit aquatic communities. Also a measure of ecological community structure.

**Ecological component** - Any part of an ecological system including individuals, populations, communities, or the ecosystem itself.

**Ecological effects** - The ability of a stressor to cause adverse effects under a particular set of circumstances.

**Ecological risk assessment** - The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

**Ecosystem -** The biotic (living) community and abiotic (nonliving) environment within a specified location in space and time.

**EEC –** Estimated exposure concentration.

**Epibenthos** - Refers to organisms (mainly invertebrates and fish) living near (just above) bottom sediments and not living in the bottom sediments.

**Exposure** - Co-occurrence of or contact between a stressor and an ecological component.

**Exposure scenario** - A set of assumptions concerning how an exposure may take place, including assumptions about the exposure setting, stressor characteristics, and activities that may lead to exposure.

**Fate** - The form and location of a chemical material resulting from transport and transformation.

**Genera** - Taxonomic category including one or more species which have certain fundamental characteristics in common.

**Lines of evidence** - Formerly weight of evidence. A discussion in the ecological risk assessment that provides the risk manager with insight about the confidence of the conclusions reached in the risk assessment by comparing the positive and negative aspects of the data including uncertainties identified during the process.

**Measure (measurement endpoint)** - A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint. Measurement endpoints are often expressed as the statistical or arithmetic summaries of the observations that comprise the measurement.

**Model** - A system of postulates, data and inferences presented as a mathematical description of an entity or the relationships of several or more variables.

**Plankton** - Microscopic plants and animals living freely or weakly swimming in surface waters.

**Population** - An aggregate of individuals of a species within a specified location in space and time.

**Probability** - The likelihood that a parameter will assume a particular state or value (e.g., The probability that exposure to a chemical will cause a fish kill is one in one hundred.

**Problem formulation** - A phase of ecological risk assessment that establishes the goals, scope, and focus of the assessment. It is a systematic planning step that identifies the major factors to be considered in the assessment and is linked to regulatory and policy requirements. Its outcome is a conceptual model that describes how a given stressor might affect the ecological components of the environment.

**Receptor** - The ecological component exposed to the stressor.

**Richness** - A measure (number of species) to characterize the variety of organisms in biological communities. Also a measure of ecological community structure.

**Risk characterization** - A phase of ecological risk assessment that integrates the results of the exposure and ecological effects analyses to evaluate the likelihood of adverse ecological effects associated with exposure to a stressor. The ecological significance of adverse effects is discussed, including consideration of the types and magnitudes of effects, their spatial and temporal patterns, and the likelihood of recovery.

**Risk management** - A phase of risk assessment that includes discussions between the risk assessor and risk manager that paves the way for regulatory decision making. These discussions ensure that the results of the risk assessment are clearly and fully presented. The results of the risk assessment process are used along with other inputs to evaluate risk management options.

**Smolt** - A salmon or trout that is outmigrating from freshwater to marine water and is adapting to marine life. The lifestage where a salmon or trout takes on the silvery color of an adult.

**Source** - An entity or action that releases to the environment or imposes on the environment a chemical, physical or biological stress or stressor.

**Stressor** - Any physical, chemical or biological entity that can induce an adverse ecological response.

**Stressor-response profile** - The product of characterization of ecological effects in the analysis phase of the ecological risk assessment. The stressor-response profile summarizes the data on the effects of a stressor and the relationship of the data to the assessment endpoint.

**Trophic level** - Functional classification of organisms in a community according to feeding relationships; the first trophic level includes green plants; the second level includes herbivores; the third level includes carnivores; and so on.

**Uncertainty** - Not having certain knowledge or lack of sureness. In the context of risk assessment, an example is the requirement to predict risk by extrapolating from general data, or to use a mathematical model based on assumptions that were not derived from local (site-specific) conditions. Also attributable to the natural variability in environmental data.

**Validation** - The testing of a model against reality.